EFFECTS OF EXPERIMENTAL PALATAL FISTULAS ON TONGUE MOVEMENT

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

2001

ACKNOWLEDGMENTS

I especially acknowledge Dr. William Williams, who served as my supervisory committee chair on this dissertation. Dr. Williams provided me with constant support, guidance, and encouragement throughout my four years as a graduate student at the University of Florida. I would also like to acknowledge Dr. Geralyn Schulz, who served as my co-chair on this dissertation. Her time, patience, guidance, and encouragement are sincerely appreciated.

I also extend special thanks to other members of my supervisory committee – Dr. Christine Sapienza, Dr. Howard Rothman, Dr. Stephen Boggs, and Dr. Paul Wharton – for their support and guidance at every step of my studies. I would especially extend thanks to Dr. Jeniffer Dutka, who patiently listened to and challenged me in endless discussion about this research.

I extend appreciation to Ms. Martha Paulk, Ms. Virginia Dixon-Wood, and Dr. Alice Dyson for their time, cooperation, and willingness to participate, in different ways, in this study. I give thanks to Kim Scott, Sarah Ahmed, Ana Mendes, Yaser Natour, and Lourenço Chacon for their helpful tips and encouragement.

I extent sincere appreciation to all of my colleagues and friends from the Department of Phonoaudiology – UNESP – Brazil for their support throughout the past four years. I also thank the financial support from the Government of Brazil/CNPq.

Last, but not least, I wish to express my heartfelt thanks to my husband, Edgard, for his constant support throughout these years in Gainesville and to my son, Felipe, for his patience while I was working on this research.

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of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

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May 2001

Chairman: William N. Williams
Major Department: Communication Sciences and Disorders

The purpose of this single-subject study was to investigate speech articulatory performance following experimentally controlled “fistulas” through a palatal obturator worn by an adult male with an unrepaired cleft of the hard and soft palate. For this, three different size holes (10 mm^2, 20 mm^2 and 30 mm^2) were drilled through an experimental palatal obturator (close replicate of the subject’s original obturator), one at a time, at two locations (anterior and posterior). The effect of an experimental palatal “fistula” over time was also investigated in this study. For this condition, tongue movement measurements were obtained after five days in which the subject had worn the experimental obturator with the 20 mm^2 anterior opening. Tongue movement for the consonants /t/ and /k/ in the initial and final position was measured using Eletromagnetic Articulography (EMA).

Analysis of the data revealed that both experimental fistula location and experimental fistula size affected tongue tip and tongue medium movement. Changes in tongue movement in the presence of anterior "fistulas" occurred more often for the velar consonant /k/ than for the linguo-alveolar consonant /t/. Changes in tongue movement in the presence of posterior "fistulas" were less often than in association with anterior "fistulas". Significant changes in tongue movement occurred for the two largest anterior and posterior "fistulas" (20 mm^2 and 30 mm^2).

Analysis of data also revealed that tongue articulatory movement was significantly affected after the subject had worn the 20 mm^2 experimental palatal "fistula" for five days when compared to tongue movement observed immediately after creating the 20 mm^2 experimental palatal "fistula". Tongue movement after five days was not different than tongue movement observed when the experimental obturator was completely occluded (control condition).

The findings of this study provide basic quantitative information on tongue kinematics as related to the presence of palatal openings. This information is critical for a better understanding and management of palatal fistulas remaining after surgical repair of cleft palate.

CHAPTER 1
INTRODUCTION AND REVIEW OF LITERATURE

Introduction

Complete or near complete separation of the nasal and oral cavities is recognized as a requisite for normal oral speech production. This separation, however, is not always achievable. Unrepaired cleft palate and velopharyngeal inadequacy (VPI), impaired neuro-motor control of the velopharyngeal structures, and faulty learning are conditions that have been identified as causal to a breakdown in the normal separation of the oral and nasal cavities (Bradley, 1997). In addition, an opening (fistula) in the hard and/or soft palate occurring as a result of a surgical breakdown may also result in inappropriate coupling between the oral and nasal cavities.

Coupling of oral and nasal cavities as it occurs in the presence of palatal fistulas is detrimental to normal oral speech production since it increases nasal airflow and, thus decreases intraoral air pressure for production of oral pressure consonants, causing distortion to theses sounds. In addition to impaired articulation due to distortions caused by the leakage of air into the nasal cavity and loss of intraoral air pressure, there is an increase in nasal resonance for nonnasal speech production. Changes in tongue placement during speech are also associated with palatal fistulas. These deviant tongue placements during speech are thought to occur as an attempt by the speaker to maintain normal pressure for consonant sounds by building up pressure while using an abnormal lingual-palatal contact (Witzel, 1995). When associated with distorted sound production caused by nasal air emission, weak pressure consonants, and hypernasality, these deviant tongue placements compromises the overall speech intelligibility even more.

Clinical observation and initial research revealed that the magnitude of the speech problems (resonance, nasal airflow, and intraoral pressure) associated with palatal fistulas depends on the size, shape, and location of the palatal opening. Quantitative descriptions of the speech problems resulting from palatal fistulas also substantiated these clinical data. Little qualitative and quantitative information on tongue movements as a result of palatal fistulas is reported in the literature. From a clinical perspective, the management of articulation disorders resulting from palatal fistulas seems to depend on a better understanding of the tongue movements involved in the speech production of individuals with palatal openings.

This study investigated changes that occur in articulatory performance in the presence of controlled openings through an experimental palatal obturator covering an unrepaired cleft of the hard and soft palate. More specifically, this study identified changes in tongue movement that occurred by experimentally manipulating size and location of these openings. A secondary interest was the possible relationship between tongue movement and the effects of experiencing an experimental opening for five days.

The following review describes palatal fistulas, the speech symptoms associated with palatal fistulas, the effects of location and size of palatal fistulas on speech production; and, finally, how palatal fistulas affect the place of articulation. A review of existing qualitative and quantitative data on deviant place of articulation resulting from palatal fistulas highlights the need for more quantitative information that describes the effect of size and location of palatal fistulas on tongue movements. This information can then guide clinical management of speech disorders related to palatal openings.

Review of the Literature

Palatal Fistulas

Palatal fistulas, as defined in this study as a hole in the palate connecting the oral and nasal cavities, are a well-known residual condition that occasionally occurs after a palatal primary surgical repair in individuals with cleft. Although the desired goal of palatal surgery is to provide closure between the oronasopharynx and the nasal passages and to promote a functional velopharyngeal system for adequate speech production, failure frequently occurs and palatal fistulas may develop (Converse, 1977; Millard, 1980). Palatal fistulas, therefore, may represent a failure of surgical technique or a problem in the healing process itself, which is usually the result of excessive tension on the repair (Amaratunga, 1988; Dufresne, 1990; Shprintzen & Sidoti, 1995).

A palatal fistula located anteriorly may also be present after some types of surgical procedures in which a portion of the original cleft is intentionally unrepaired. This is usually the case where the original cleft is too large for closure to be completed by a single procedure (Cohen et al., 1991; Folk, D'Antonio, & Hardesty, 1997; Oneal, 1971). Additionally, fistulas that are asymptomatic in early childhood may increase in size as a result of orthodontic expansion of the maxillary segments or growth process, resulting in speech symptoms (Åbyholm, Borchgrevink, & Eskeland, 1979; Bardach, 1995).

Palatal fistulas have been referred to as "primary"–that is, present after repair of the cleft palate–or "recurrent," which are defects after repair of an existing fistula. Recurrent palatal fistulas are usually associated with scar tissue and with multiple previous palatal incisions (Folk, D'Antonio, & Hardesty, 1997). Whether primary or recurrent, palatal fistulas correspond to a surgical complication of major concern because of the speech problems they may cause (Shprintzen & Sidoti, 1995).

Loss of liquid or food into the nasal cavity while eating is the most common described symptom associated with palatal fistulas (Åbyholm, Borchgrevink, & Eskeland, 1979; Aramatunga, 1988; Converse, 1977; Hennigsson & Isberg, 1990; Leeper, Sills, & Charles, 1993; McWilliams, Morris, & Shelton, 1990; Oneal, 1971; Palmer et al., 1969; Rintala, 1980; Schultz, 1986). Inflammation of the mucosa has also been observed in the presence of palatal fistulas as a result of the particles of food that may remain lodged in the fistula (Åbyholm, Borchgrevink, & Eskeland, 1979; Lehman, 1978).

Hypernasality (Aramatunga, 1988; Henningsson & Isberg, 1987; Golding-Kushner, 2001; Jackson, Jackson, & Christie, 1976; McWilliams, Morris, & Shelton, 1990; Palmer et al., 1969; Reid, 1962; Ross & Johnson, 1972), nasal air emission (Bless, Ewanowski, & Dibbell, 1980; Henningsson & Isberg, 1987; Jackson, 1972; Jackson, Jackson, & Christie, 1976; Oneal, 1971; Morley, 1970; Palmer et al., 1969; Schultz, 1986), and weak pressure of consonants sound (Henningsson & Isberg, 1987; Jackson, Jackson, & Christie, 1976; Morley, 1970; Rintala, 1980; Schultz, 1986; Shelton & Blank, 1984) are the speech symptoms most often reported in association with palatal fistulas. Abnormal tongue placement (compensatory articulation) during production of pressure consonants is also related to the presence of palatal fistulas (Golding-Kushner, 1995; 2001; Hoch et al., 1986; Schultz, 1986; Trost, 1981; Witzel, 1995). When present, these speech symptoms may impair the individual's speech intelligibility.

Palatal fistula(s) after the primary palatal surgical repair of the cleft are a source of concern for professionals involved in the management of individuals with cleft palate.

Such palatal fistula(s) may require additional surgical management to resolve the problems of loss of food into the nasal cavity and speech disorders (Shprintzen & Sidoti, 1995). Therefore, we need to understand why palatal fistulas occur as well as their consequences on speech.

Palatal fistula characteristics

Fistulas between the oral and nasal cavities may occur anywhere along the site of the original cleft (Dufresne, 1990; Lindsay, 1971; Schultz, 1986). However, the majority occur in the anterior portion of the hard palate, primarily in the region of the incisive foramen (Bardach & Salyer, 1995; Cohen et al., 1991; Henningsson & Isberg, 1990; Leeper, Sills, & Charles, 1993; Lindsay, 1971; McWilliams, Morris, & Shelton, 1990; Palmer et al., 1969; Reid, 1962). The second most common location of oronasal fistulas is at the junction of the hard and soft palate (Bardach & Salyer, 1995; Henningsson & Isberg, 1990; Oneal, 1971). Fistulas in the soft palate are much less common (Lindsay, 1971). Any combination of these defects, however, can occur (Peterson-Falzone, Hardin-Jones, & Karnel, 2001).

Palatal fistula(s) may also vary in shape, size, and three-dimensional structure. They have been described as being pinpoint, slit-shaped, oval, round, triangular, or a near recurrence of the original cleft after complete dehiscence of the palatal repair (Folk, D'Antonio, & Hardesty, 1997). In general, palatal fistula size is reported to range from small to large (Cohen et al., 1991; Gordon & Brown, 1980; Henderson, 1982; Henningsson & Isberg, 1987; Isberg & Henningsson, 1987; Morley, 1970; Proctor, 1969; Reid, 1962; Shelton & Blank, 1984). However, discrepancies exist as to what is considered a small, medium or large fistula. The variety in fistula descriptions such as those related to their size result from the different procedures used to examine fistula characteristics.

Qualitative information and quantitative measures of length, width, and/or area have been used to categorize fistula size (Henningsson & Isberg, 1987; Krause, Tharp, & Morris, 1976; Schultz, 1986; Shelton & Blank, 1984;). Procedures such as intraoral examination, intraoral photographs, and plaster dental casts have all been commonly used to allow for some information on the size and location of a fistula. However, as pointed out by Clark et al. (1992), these methods do not always indicate the vertical (inferior-superior) course or "three-dimensional nature" of palatal fistulas.

By using radiographic imaging, Clark et al. (1992) investigated the size, shape, location, and course of a variety of patent, symptomatic palatal fistulas presented by five subjects with repaired cleft palates. Qualitative descriptions of the inferior-superior course and the location and size of the narrowest aperture of palatal fistulas were obtained with the combination of maxillary occlusal, posterioanterior, and lateral tomographic projections (which provided the three-dimensional measurements) as well as with the use of barium sulfate contrast. The results of this study showed that intraoral dimensions of the fistulas obtained by using descriptions and measurements from plaster dental casts, intraoral photographs, and clinical examinations were generally unrelated to the narrowest and widest dimension of the palatal fistulas measured by radiographic images. Clark et al. (1992) concluded that intraoral judgments/measurements do not characterize the fistula adequately and estimating the size and location of palatal fistulas only by oral examination may interfere with determination of the clinical significance of the palatal fistulas in terms of their function and management. They further stated that "…information of the location and size of the narrowest aperture of the fistula may be valuable to the speech pathologist to understand the potential role the fistula may have in overall speech symptoms" (page 662).

The "three-dimensional nature" of a palatal fistula and the need to view fistulas as more than simply openings of a given diameter or location also were stressed by Folk, D'Antonio, & Hardesty (1997). According to these authors, the course of a fistula is often irregular and the narrowest part of the opening may not be observable from the oral surface; however, the fistula may have a great influence on function. Therefore, the authors pointed out that simply estimating the size of the fistula from the intraoral view alone might have clinical consequences. They added that radiographic examination with the use of contrast may reveal valuable additional information regarding the "three-dimensional course" of a palatal fistula. However, its clinical indication is limited by cost and radiation exposure. The authors, therefore, suggested the use of either "gentle probing" or transillumination by placing a nasopharyngoscope in the nose to help to discern between a fistula and a blind pouch, which is even more difficult to determine when an intraoral view is used as the only method of observation.

The studies reported above described a wide variability in fistulas. Professionals who are involved with the management of individuals with cleft palate, therefore, should be aware of this variability. More important, surgical, dental and speech clinicians should be alert to the need for comprehensive evaluations that investigate the effects of fistulas on speech (Folk, D'Antonio, & Hardesty, 1997).

Incidence of palatal fistulas

The reported incidence of fistulas after surgery in individuals with cleft palate has varied considerably. In a review of early literature regarding postsurgical fistula formation, Musgrave (1960) found rates of "surgical failure" up to 80%. Since the art and science of palatal surgery have changed remarkably through the years, a lower incidence of palatal fistulas has been reported in later literature. In a review of fistula rates, Oneal (1971) found the incidence of surgical failure to be between zero and 21%. Ross & Johnston (1972) found that fistulas after surgical cleft repair ranged from 10 to 20%, depending on different surgical techniques and cleft type, as well as different sample selections on the existing studies. Postsurgical occurrence of the fistulas in individuals with cleft palate was reported to be as high as 18% by Åbyholm and co-works (1979). Schultz (1986) reported postoperative fistulas in 22% of 199 patients while Amaratunga (1988) found oronasal fistulas after cleft palate repair in 21% of the 346 cases investigated. Dufresne (1990) summarized the incidence of oronasal fistulas as varying from 5% to 29%.

In an attempt to clarify the prevalence of fistulas followed by palatal surgical repair, Cohen et al. (1991) examined the rate of fistula occurrence according to (1) severity of the original cleft, (2) type of palatoplasty, (3) age at palatal surgery, and (4) the specific surgeon doing the palatoplasty. They found 30 fistulas in 129 (23%) consecutive cases of palatal clefts. The majority of these fistulas were located at the hard palate. The authors did not include patients in whom there was either a nasal-alveolar fistula or an anterior palatal fistula that had been intentionally left unrepaired. Four categories of severity, four surgeons, four types of palatoplasties, and three types of soft palate surgical closures were included in the study (4 x 4 x 4 x 3), yielding 192 possible combinations distributed across the 129 patients. A multivariate statistical analysis was then used to determine the incidence of postoperative fistulas. Results obtained in this study showed significant effects on fistula occurrence when categories of severity of the original cleft, type of palatoplasty, and the specific surgeon doing the palatoplasty were analyzed. The factor of age at time of surgery showed no statistically significant difference.

The above reports reveal that the incidence of fistula varies greatly across surgeons and cleft centers and depending on the surgical techniques used, and the severity of the original cleft.

Types of cleft and palatal fistulas

Palatal fistulas may occur after palatoplasty for treatment of unilateral and bilateral complete clefts of the lip, alveolus, and palate as well as for treatment of cleft palate only (Dufresne, 1990). According to McWilliams, Morris, & Shelton (1990), clefts involving only the soft palate seem less likely to develop a fistula after surgical repair than do other types of clefts. They cited Peer et al. (1954) who found no fistulas associated with soft palate repair as compared to a 14.8% occurrence rate associated with other types of deformities. In a study comparing two types of palatal surgical procedures (Von Langebeck and palatal pushback), Palmer et al. (1969) also found no fistulas associated with cleft soft palate only. Additionally, these authors found more fistulas associated with bilateral clefts (23% and 21%) than unilateral clefts (16% and 10%) for each type of surgery, respectively. Lindsay (1971) also reported no fistulas associated with cleft of the palate only as compared to a rate of 15% and 20% for unilateral and bilateral clefts, respectively. Musgrave & Bremer (1960) and Åbyholm, Borchgrevink, & Eskeland (1979) reported lower incidence of fistulas for incomplete clefts than completes. Aramatunga (1988) found more fistulas associated with bilateral than unilateral clefts. Cohen et al. (1991) reported that fistulas occurred more often in individuals with more severe clefts.

Individuals with severe clefts, such as bilateral complete clefts, would likely develop fistulas secondary to surgical repair more frequently than would patients with a simpler type of cleft.

Type of palatal repair and palatal fistulas

The type of surgical repair of palatal clefts also represents a factor that may influence the occurrence of a fistula. Some authors reported that residual fistulas occur more often after von Langenbeck surgeries than after palatal pushback (Amaratunga, 1988; Krauser, Tharp, & Morris, 1976; Lindsay, 1971; Palmer et al., 1969). In the study conducted by Palmer et al. (1969), the authors found that the residual fistulas after von Langenbeck procedure not only occurred more often but also were slightly larger than those resulting from the pushback procedure. Lindsay (1971) reported a 16 and 23% incidence of fistulas for unilateral and bilateral clefts, respectively, after von Langenbeck surgery was performed on 60 individuals with palatal cleft. The author also found the corresponding percentages of fistulas to be 10 and 21%, when the pushback procedure was performed in a group of 45 patients. Åbyholm, Borchgrevink, & Eskeland (1979) reviewed 1108 individuals who had von Langebeck procedures between 1954 and 1969 and found the incidence of the fistulas to be as high as 18%. Amaratunga (1988) found oronasal fistulas in 73 of 346 individuals who had their cleft repaired by either von Langenbeck or Wardill's (palatal pushback) technique. The author further reported that Von Langenbeck procedures resulted in more oronasal fistulas (43 individuals) than the Wardill procedure (30 individuals).

Other authors have reported that residual fistulas occur more often after a palatal pushback. Reid (1962), for example, commented that a large residual fistula (greater than two centimeters) would follow pushback surgery. Van Demark (1974) also reported greater occurrence of fistula after a V-Y procedure (palatal pushback) as compared to the von Langenbeck technique. Moore (1988) reports postsurgical fistulas in 11 (6%) of 196 patients, which were slightly more frequent in those patients who had received Wardill-Kilner palatoplasty (palatal pushback).

Cohen et al. (1991) found a total of 30 fistulas in the 129 consecutive cases of palatal clefts that they investigated. With respect to type of palatoplasty, the authors reported a 43% fistula rate with the Veau-Wardill-Kilner pushback procedure, 10% with the Furlow double opposing Z-plasty, 22% with the von Langenbeck procedure, and 0 with the Dorrance pushback.

In contrast with the reported studies, some authors indicated that more residual palatal fistulas occur when either the von Langenbeck palatoplasty or the Wardill-Kilner techniques are performed than after the two-flap palatoplasty (Bardach & Salyer (1995). This is supported by studies conducted at the Iowa Cleft Palate Center. As reported by Bardach and Salyer (1995), findings obtained from a particular study, published in 1992, which included individuals with bilateral cleft of lip, alveolus and palate, indicated that only five individuals of 50 (10%) had an oronasal fistula in the anterior palate after two-flap palatoplasty. The authors concluded that, when performed with care and technical skill, two-flap palatoplasty results in complete closure of the palatal cleft with minimal frequency of oronasal fistulas and also provide adequate functioning velopharyngeal mechanism.

Residual palatal fistulas as a result of surgeries designed to close the soft palate have also been reported in the literature. The study conducted by Gunther et al. (1998), which included children with all types of clefts who had had the hard portions of the clefts repaired either by modified von Langenbeck or Wardill procedures, indicated that more postsurgical fistulas occurred after Furlow double-reversing Z-plasty than intravelar veloplasties.

From these reports one can conclude that a fistula may occur in any surgical series. As stated by McWilliams, Morris, & Shelton (1980), "the prevalence of fistula, even today, varies widely from surgeon to surgeon, from cleft type to cleft type, and perhaps from procedure to procedure" (page 67).

Surgical and prosthetic treatment for palatal fistulas

Surgical repair has been reported as the treatment of choice for repair of palatal fistulas (Lehman, 1978; Shprintzen & Sidoti, 1995). A number of techniques have been described for fistula closure. The choice of approach for repair appears to be based on fistula size and location (Jackson, 1972; Rintala, 1980) as well as history of the defect (initial versus recurrent) (Folk, D'Antonio, & Hardesty, 1997). As summarized by Peterson-Falzone, Hardin-Jones, & Karnell (2001) the surgical approach may include the following: "(a) local "turnover" flaps, (b) various versions of "island" mucoperiosteal flaps of palatal tissue, (c) buccal flaps (from the inside of the cheek), and (d) "tongue flaps"(a portion of the mucosal surface of the tongue)" (page 111). The authors also stated that for fistula located more posteriorly in the palate, a very long pharyngeal flap may be the treatment choice since this surgical approach closes the fistula and decreases the size of the velopharyngeal port.

Some fistulas can be surgically repaired while others may be so large that surgical closure is very difficult (Leeper, Sills, & Charles, 1993). The presence of scar tissue in the operative site, that usually results from all types of surgery (Leeper, Sills, & Charles, 1993; Peterson-Falzone, Hardin-Jones, & Karnell, 2001) and the lack of "virgin local tissue" (Witt & D'Antonio, 1993), also interfere with the successful closure of the fistulas. Difficulties in re-operating on scarred tissue have been reported as causal for the relatively high recurrence rates of operated fistulas (Cohen et al., 1991; Oneal, 1971; Peterson-Falzone, Hardin-Jones, & Karnell, 2001). Therefore, as Witt & D' Antonio (1993) stated, "in clinical practice, many surgeons will repair only those fistulas that they believe are likely to be most symptomatic" (page 716-717).

A variety of opinions have been expressed in the surgical literature concerning which fistulas are likely to be symptomatic. Usually, large, patent fistulas are associated with significant symptoms such as regurgitation of fluid to the nasal cavity and speech problems requiring surgical treatment for closure (Folk, D'Antonio, & Hardesty, 1997; Randall, 1986). The effects of smaller-appearing fistulas, however, also have been discussed in the literature. Although some authors related small fistulas with speech symptoms (Henningsson & Isberg, 1987; Schultz, 1986; Shprintzen & Sidoti, 1995) others reported that small fistulas do not often have any impact on speech (Randall, 1986; Oneal, 1971).

The diversity of descriptions of speech results in association with small fistulas may be explained by some factors such as the "three-dimensional nature" of the fistulas as well as their interaction with other structures of the vocal tract. As Folk, D'Antonio, & Hardesty (1997) explained "the size of a fistula on intraoral examination does not predict its interaction with the nasal cavity, tongue, or velopharynx, and, therefore, does not predict its functional significance" (page 602). These authors further stated that changes in velopharyngeal function after temporary (Bless, Ewanowski, & Dibbell, 1980; Isberg & Henningsson, 1987) and long-term fistula occlusion (Pinborough-Zimmerman et al., 1997) suggested a more complex interaction between fistula characteristics and their symptoms.

The complex interaction between fistula characteristics and speech symptoms was clearly demonstrated in the studies conducted by Isberg & Hennigsson (1987) and Henningsson & Isberg (1987). These studies, respectively, investigated velopharyngeal activity and speech results in ten individuals with hypernasality while producing speech samples with the fistula alternately open and occluded. Fistulas of different lengths, widths, and areas located in the hard palate were included for study. Videofluoroscopic images of velopharyngeal activity during speech showed increased movement with the fistula occluded in all ten patients. The improvement on velopharyngeal movements during speech production was consistent with the improvement on speech and nasal resonance. The authors concluded that a palatal fistula can impair velopharyngeral activity for an individual who demonstrates adequate function, exacerbating existing velopharyngeal inadequacy. Other authors (Bless, Ewanowski, & Dibbell, 1980; Karling, Larson, & Henningsoon, 1993; Lohmander-Agerskov et al., 1996; Tachimura et al., 1997) demonstrated that obturating a fistula may result in improved velopharyngeal valving.

A comprehensive evaluation of speech symptoms related to palatal fistulas, therefore, is necessary in order to determine the need and benefits from their closure. This evaluation is accomplished by (1) asking the patient to repeat the speech material with the fistula open and temporarily covered, and (2) selecting speech samples that facilitate the interpretation of the speech quality resulting from the "covered" and "uncovered" condition (Henningsson & Isberg, 1990). A temporary obturation of oronasal fistulas located in the hard palate–and most often in the area of the incisive foramen–can be achieved by using dental wax (Bless, Ewanowski, & Dibbel, 1980), chewing gum (Isberg & Henningsson, 1987), or a skin barrier adhesive patch, as suggested by Reisberg, Gold, & Dorf (1995). By comparing speech quality while the speaker has the fistula open and covered, information regarding the effects on an oronasal fistula on speech can be drawn. As Henningsson & Isberg (1990) explained,

> if the "uncovered" findings indicate nasalization and the "covered" findings do not, the inference can be made that the fistula is the main contributor to the nasalization disorder. If nasalization occurs in both conditions, the inference must be made that the nasalization is the result of dysfunction of the velopharyngeal mechanism (page 787).

The speech samples selected for evaluation of the influence of fistula on speech should include words loaded with pressure consonants that are articulated both anterior to ("prefistula"- e.g. /t/) and posterior to the fistula ("postfistula" – e.g. /k/). As Peterson-Falzone, Hardin-Jones, & Karnell, 2001) summarized,

> "in theory, if the fistula is the sole route of nasal air loss, that loss will occur only on consonants anterior to the location of the fistula. If all pressure consonants continue to be produced with nasal air loss, it is possible that the cause is inadequate velopharyngeal function and not the fistula alone (page, 111).

The importance of determining whether the speech symptoms are exclusively a result of fistula or are also associated with VPI is crucial for treatment decision. If obturation of the fistula indicate complete VP closure or even a small residual VP gap, a surgery or prosthetic obturation of only the fistula is recommended. However, if a large residual VP gap is still present after occluding the fistula, a surgery procedure combining the fistula repair plus secondary palatal management is usually the treatment of choice

(Folk, D'Antonio, & Hardesty, 1997). The functional significance of any palatal fistula, therefore, must be evaluated for each patient individual before making any surgical or prosthetic treatment decision (McWilliams, Morris, & Shelton, 1990; Oneal, 1971; Shelton & Blank, 1984; Witt & D'Antonio, 1993).

A temporary or permanent prosthetic obturation of oronasal fistulas may be also a solution for the treatment of oronasal fistulas for some patients (Aramatunga, 1988; LeBlanc & Cisneros, 1995; Leeper, Sills, & Charles, 1993; Thompson, Ferguson, & Barton, 1985). This indication occurs most often in cases of recurrent fistulas and when serving as an interim obturator while awaiting surgery or orthodontic treatment (Folk, D'Antonio, & Hardesty, 1997). A dental appliance may also be used to cover a fistula that is detected immediately after surgical repair. The use of a dental appliance to cover the newly formed opening often promotes its closure by spontaneous formation of fibrous scar tissue (Sphrintzen & Sidoti, 1995). Additionally, small fistulas that do not cause a significant speech disorder may be temporarily obturated to prevent food and liquids from entering the nasal cavity during eating and drinking.

The reported literature shows that surgical and prosthetic correction of palatal fistulas relies on information related to the effects of fistula on speech. Therefore, we need to understand the speech problems that result from palatal fistulas when evaluating and/ or treating patients with this palatal condition.

Speech Production and Palatal Fistulas

Speech production of individuals with palatal fistulas may be associated with the following: a) hypernasality; b) nasal air emission; c) weak pressure consonants (Heningsson & Isberg, 1990; Golding-Kushner, 2001); d) presence of an extra acoustic, whistling component associated with the speech sound (Heningsson & Isberg, 1990) and, e) abnormal tongue placement during production of pressure consonants (Golding-Kuhsner, 1995, 2001; Witzel, 1995).

Hypernasality, as described by Bzoch (1997), is the acoustic resonance effect in voice quality that results from the atypical coupling of nasopharyngeal and oral /pharyngeal cavities during production of voiced sounds. That is, when produced under VPI and/or palatal fistulas, oral speech is generally associated with the presence of excessive, undesirable, or unacceptable nasal resonance (Baken & Orlikoff, 2000; Case, 1996). The elements of speech distorted by this condition include vowels and voiced consonants (Aronson, 1990; Baken & Orlikoff, 2000; Bzoch, 1997; Nicolosi et al., 1983). The glides or liquids are the most affected consonants (Bradley, 1997; Witzel, 1995).

Nasal emission is an articulation disorder that occurs when VPI and/or palatal fistulas are present during production of consonants requiring the impounding of intraoral air pressure, that is, all consonants in English except liquids, glides and nasals (Bzoch, 1997; Peterson-Falzone, 1986; Witzel, 1995). This nasal air escape may be detected (on a mirror) and, in more serious cases, may be audible while the air passes through the nasal passage (audible nasal emission) (Peterson-Falzone, Hardin-Jones, & Karnel, 2001).

The presence of an acoustic component ("whistling" sound) is a particular symptom generated in the presence of a fistula. As explained by Henningsson & Isberg (1990), the air leakage that occurs during speech sounds that are articulated anterior to the fistula often gives rise to an extra acoustic component associated with the speech sound, influencing the speech production. Henningsson & Isberg (1990) describe this acoustic component as being "a bubbling sound or, more frequently, a high-frequency fricative sound with a slight whistling quality" (page 788). These authors also reported that intraindividual variation exists regarding the occurrence and intensity of this deviant whistling sound. Based on Henningsson's & Isberg's (1990) clinical experience, the deviant sound is perceived only when the fistula is small and is even more pronounced if the fistula is circular in shape, other factors being equal.

Weak pressure consonants is an error of manner of articulation that results from the inadequate oral air pressure for the production of pressure consonants – the plosives, fricatives, and affricatives (Bzoch, 1997).

Errors on place of articulation associated with palatal fistula are characterized by the use of unusual tongue gestures during production of pressure consonants. These errors are thought to occur in response to an open fistula that prevents adequate tongue placement for production of these pressure sounds. A detailed description of compensatory articulations related to oronasal fistulas is addressed later in this chapter.

The speech problems demonstrated by individuals with palatal fistulas, however, are not always present. Variations on speech behavior among individuals with abnormal oronasal coupling that occurs during the period of speech and language development may explain why speech problems are not always associated with palatal fistulas (Henningsson & Isberg, 1990). When present, however, a symptomatic fistula may cause deterioration in speech quality and intelligibility, and it can lead to significant communication impairment (Witt & D'Antonio, 1983).

Controversy exists regarding the extent of the effects of palatal fistulas on speech. As Peterson-Falzone, Hardin-Jones, & Karnell (2001) summarized, "the effects [of palatal fistula] on speech will be dependent at least on the size of opening, the location, and the developmental time in the child's acquisition of communication skills in which the fistula is or was present" (page 110). The relationship among speech symptoms as associated with size and location of palatal fistulas is reported below.

Palatal fistula size and speech

Most of the studies that investigated the relationship between size of fistula and speech outcome are based only on clinical evidences. These studies suggested that while small fistulas may be nonsymptomatic for speech (Krause, Tharp, and Morris, 1976; Oneal, 1971; Randall, 1986) moderate and large fistulas often result in audible nasal emission and weak pressure with or without hypernasality (Shelton & Blank, 1984). The few studies, however, that attempted directly to correlate size of fistula and speech outcome demonstrated that even a small fistula can have an impact on speech (Henningsson and Isberg, 1987; Karling, Larson, and Henningsson, 1993). Additionally, one experimental investigation examining the effects of location and size of controlled openings (fistulas) through the hard and soft palates on speech articulation and resonance also showed mild distortions associated with small fistulas with greater distortions occurring with increased openings (Richtner, 1986). Another study focusing on the investigation of respiratory, laryngeal, and supralaryngeal function associated with experimental couplings of the oral and nasal cavities ("fistulas") also revealed a consistent increase of nasal airflow with a concomitant decrease in intraoral pressure as the size of the experimental holes increased (Sapienza et al., 1996).

In the past, fistula size was described only in a qualitative manner. Morley (1970), for example, reported that even a "small" fistula might affect the development of normal speech. This occurs because of a prevention of the build-up of intraoral air pressure necessary for the production of oral consonants. Although no quantitative information as related to the size of the fistula is given by Morley, the effect of a fistula on speech is clearly stated. Other authors, however, expressed the opinion that a small palatal fistula has no effect on resonance (Krause, Tharp, & Morris, 1976; Randall, 1986; Oneal, 1971).

Shelton & Blank (1984) conducted aerodynamic assessments in six patients, Shelton & Blank (1984) reported the effects of palatal fistulas on speech in two conditions: with and without palatal obturation. Palatal obturation was achieved in this study by using either acrylic or dental appliances, dental wax, or denture adhesive. In general, the authors found that anterior consonants were more affected by open fistulas than posterior consonants. When the fistulas were not obturated, nasal air emission was found for all patients investigated. A loss of intraoral air pressure was also observed for all patients with large fistulas but was not systematically found for those with small or moderate fistula when the fistula were not obturated. That is, patients with small and moderate fistulas could maintain sufficient intraoral air pressure for adequate oral sound production. It was suggested that subjects having moderate fistulas could retain the necessary intraoral air pressure at the expense of air leakage through the fistula that was sometimes sufficient to generate noises. Although Shelton and Blank did not quantify fistulas but simply described them as being either small, moderate, or large, they speculated that patients with small and moderate fistulas may have had to increase respiratory effort to maintain oral pressures.

Quantitative definition of size of fistulas in relation to speech disorders was seldom described in earlier investigations. The studies that attempted to quantify palatal fistulas size in the past were all describing fistula size in relation to surgical techniques (Henderson, 1982; Proctor, 1969; Reid, 1962). In these studies, palatal fistulas were categorized grossly as small, moderate-sized, or large. Reid (1962) described small holes as being less than two centimeters in diameter and a large hole as being more than two centimeters in diameter. Speech defects (nasal air escape and an increased nasal voice quality) were only associated with larger fistulas. Proctor (1969) defined large oronasal fistulas as ranging from 0.5 cm to 2.5 cm but did not offer any information on other sizes. Henderson (1982), on the other hand, defined small fistulas as ranging from 0.5 cm to 1.5 cm in width and 0.5 cm to 2.0 cm in length, but failed to offer any information on large fistulas. Åbyholm, Borchgrevink, & Eskeland (1979) described larger fistulas as being bigger than 1.0 cm while small fistulas were reported to be "narrow slits wide enough only to admit a slender probe" (page 296). The authors further stated that symptoms such as nasal escape and hypernasality were associated with large fistulas while articulatory defects (diminished pressure during production of plosive consonants) were associated with small fistulas. Gordon & Brown (1980) who discussed very small and moderate-sized fistulas reported small hole as being less than a few millimeters. The authors, however, did not offer any additional information on moderate-size defects. Schultz (1986) reported small fistulas as being less than one centimeter. In his study on management and timing of cleft palate fistula repair, Schultz did not find a consistent correlation between speech symptoms and either size or location of the fistula. The author stated that even very small fistulas were occasionally symptomatic.

In a review of more recent literature reporting on palatal fistulas, few studies dealing with quantification of palatal fistulas and their influence on speech were found (Hennigsson & Isberg; 1987; Karling, Larson, & Henningsson, 1993; Richtner, 1986). Additionally, one single study reported the effects of experimental "fistulas" of different sizes (10 mm^2, 20 mm^2 and 30 mm^2) on respiratory and laryngeal function (Sapienza et al., 1996).

Richtner (1986) investigated the effects of controlled palatal fistulas on the speech of an adult that had worn a speech obturator throughout his life to cover his unrepaired clef of the hard and soft palates. In her study, Richtner experimentally manipulated size and location of openings through the subject's removable palatal obturator and measured the effect of these openings on the individual's speech articulation, resonance quality, and pressure and airflow. More specifically, experimental openings of 5 mm^2, 10 mm^2, 20 mm^2, and 30 mm^2 were drilled in the removable palatal obturator at four locations - anterior, middle, and posterior part of the hard palate and at the speech bulb, all along the midline. Six judges with experience in treating speech of individuals with cleft palate/VPI perceptually evaluated the effect of each hole size and location on the individual's speech articulation and resonance. Five perceptual tests were used in this experiment including (1) one standardized test of articulation, (2) one articulation rating test, (3) one standardized test of hypernasality without auditory masking; (4) one standardized test of hypernasality with auditory masking noise; and (5) one hypernasality rating test. Nasal airflow, intraoral air pressure, and differential pressure were measured instrumentally.

Richtner's findings revealed that hole size and location of the experimental openings (fistulas) determined the degree of speech impairment. Regarding size of the fistula, greater distortions occurred with increased openings. However, as stated by Richtner (1986), even openings as small as 5 mm^2 introduced negative effects that interfered with normal speech production. That is, articulatory inadequacy characterized as inconsistent, imprecise or distorted due to the nasal emission were found for such small openings. Nasal resonance was registered inconsistently as slightly nasal. Although perceptual tests showed small changes in speech production for openings of 5 mm^2, the speech errors were not statistically significant. Instrumental tests such as intraoral pressure and differential pressure, however, showed significant measures changes with the introduction of openings as small as 5 mm^2.

Openings of 10 mm^2 produced larger increment of errors for all five perceptual tests while openings as large as 20 mm^2 caused significant increase in errors. When analyzing the effects of the 30 mm^2 condition, a nonlinearity was observed in the form of an apparent leveling off in the error count in almost all perceptual studies, which was further confirmed by the instrumental test results. Richtner concluded that an opening as small as 5 mm^2 introduces negative effects that interfere with speech production, however, the critical size lied between 10 mm^2 and 20 mm^2. Additionally, the results showed that instrumental measures captured speech problems before listeners perceived them.

In their study, Hennigsson & Isberg (1987) reported that a fistula as small as 4.5 mm^2 in area had a definite impact on speech and resonance, resulting in hypernasality, audible nasal escape, and weakness of pressure consonants that are articulated anterior to the fistula. The effects were evaluated by comparing the perceptual examination of speech outcome of 10 individuals with the fistula open versus results with the fistula temporarily covered by chewing gum. Fistula characteristics were obtained from maxillary casts made for each patient. Fistula length, maximal width, and total size were then measured on a 1:1 print of the cast using cross-ruled millimeter paper. In their limited sample, no significant correlation was found among any of the characteristics: fistula length, width, and area, and the speech parameters examined. Based on these results, the authors argued against the findings obtained previously by Shelton and Blank who suggested in their article of 1984 that an increase in respiratory effort could compensate for small fistulas, leaving pressure consonants unaffected, while in patients with moderate fistulas the necessary intraoral pressure would result in air leakage through the fistulas. As Hennigsson & Isberg (1987) reported even small fistulas can compromise speech production. In a 1990 paper, Henningsson & Isberg further reported that their clinical experience indicated that a fistula of "only a few mm^2" might have an effect on articulation and speech.

Karling, Larson, & Henningsson (1993) examined the relationship between size and site of anterior palatal fistula and their influence on speech in three groups of patients: 18 with a fistula affecting speech, 26 with a fistula not affecting speech, and 58 without a fistula. Dental impressions were taken from all patients and the site and size of the fistula were indicated on graph paper with calipers. The size of a fistula was measured in mm^2 while the location of the fistula was determined by measuring the distance (in mm) between the most anterior edge of the fistula and the posterior surface of the upper incisors. Speech samples including consonants articulated anteriorly to the fistula were used for the perceptual and instrumental (NORAM) analysis. Additionally, when nasal air emission was observed, consonants articulated posteriorly to the fistula (for example, /ka-ka-ka/) were also included. If the nasal air emission disappeared while articulating velar consonants, the fistula was considered to affect speech. If the effects of the fistula were not clearly determined, a chewing gum was used to temporarily cover the fistula. When changes in hypernasality and nasal air emission occurred (after the chewing gum was introduced), the fistula was then considered to affect speech. The results obtained in this study showed that anterior fistulas measuring as little as 2 mm^2

could affect speech. Additionally, it was observed that larger fistulas were found more in the affected speech group than the non- affected speech groups. The authors concluded that the larger the fistula, the greater the risk of causing hypernasality and nasal air emission. However, they also pointed out that even small fistulas could result in speech problems.

The study conducted by Sapienza et al. (1996) investigated the respiratory and laryngeal function associated with experimental coupling of the oral and nasal cavities ("experimental fistulas"). In this study, three experimental openings (10 mm^2, 20 mm^2, 30 mm^2) were placed one at time in a subject's palatal obturator at the location approximating the junction of the prepalate and the palatal shelves. Acoustic and aerodynamic measures (fundamental frequency, sound pressure level, nasal ariflow, and intraoral air pressure) as well as respiratory measures of lung, rib cage, and abdominal volumes were obtained while the subject produced a series of CV syllables [pa]. These syllables were repeated at a comfortable and loud vocal intensity for each of the three experimental conditions. Two more conditions, one in which the palatal obturator was completely occluded and another in which the subject did not wear the obturator were also included for the study. The results obtained showed laryngeal and respiratory adjustments occurring as oronasal coupling increased (by increasing the size of the hole through the palatal obturator and in a nonobturator condition) during the loud syllable production. Laryngeal adjustment, as measured by fundamental frequency, was the most identifiable change and was though to occur to assist in generating the vocal intensity required for the loud speech task. An increase in nasal airflow with a concomitant decrease in intraoral pressure as the degree of oronasal coupling increased was also observed. That is, as the degree of oronasal coupling increased, with a subsequent increase in nasal airflow, the subject's ability to raise intraoral air pressure for the loud speech task deteriorated but never reached below 3 cm H_20. As the authors explained, the respiratory measures indicated an attempt by the subject to utilize his respiratory system to maintain adequate pressure as oronasal coupling was increased and loudness level was raised. A respiratory adjustment, which involved the expenditure of more lung volume as nasal airflow leakage increased, was also noted in this study. This respiratory adjustment was thought to occur as an active response necessary for achieving and maintaining the aerodynamic regulation of airflow for the loud speech task.

As reported a large variation exists on the data reporting on the impact of fistula size on speech production. Furthermore, the relationship between fistula size and its effects on place of articulation is still not well documented in the literature.

Palatal fistula location and speech

Palatal fistulas located in the hard and /or soft palate have been related to various speech symptoms (Henningsson & Isberg, 1990). However, there still exist some questions about the relationship between palatal fistula location and speech defects.

Some studies suggested that palatal fistulas occurring in the anterior palate exert significant negative influence on speech production (Bless, Ewanowlski, & Dibbell, 1980; Cosman & Falk, 1980; Hennigsson & Isberg, 1987; Karling, Larson & Henningsson, 1993; Lindsay, 1971; Palmer et al., 1969; Shelton & Blank, 1984). Another report merely indicated a possible existence of speech disorders resulting from anteriorly located fistulas (Ross & Johnston, 1972). None of these studies, however, provided specific details on which are these negative effects. Fistulas occurring posteriorly in the hard palate or in the soft palate, however, were reported to result in the same type of speech problems that are associated with cleft palate (e.g. hypernasal resonance and audible, inappropriate nasal air emission) (Ross & Johnston, 1972). In an experimental study conducted by Richtner (1986), greater distortions of articulation and resonance quality were found to occur in association with openings located at the region of the speech bulb (that is, the area representing the soft palate). Regarding anterior openings, greater speech problems were found to occur when the openings were located near the region of the foramen incisive (Richtner, 1986). A more recent report indicated that fistulas located at the soft palate result in speech deviations that are similar to those found for a fistula in the hard palate (Hennigsson & Isberg, 1990).

In their respective studies, Palmer et al. (1969) and Lindsay (1971) found that postsurgically, palatal fistulas situated in the anterior portion of the hard palate were a source of audible nasal air emission, impairing articulation proficiency. These palatal fistulas also were said to cause slight nasality (Palmer et al., 1969; Lindsay, 1971). The study conducted by Shelton & Blank (1984) which provided quantitative data on the effects of palatal fistulas in six patients who had either one or two fistulas located at various sites in the hard palate also showed presence of nasal air flow resulting from palatal fistulas. Additionally, a drop in intraoral pressure were also found in association with anterior palatal fistulas, with greater effects on /p/ and /f/ than on /k/.

In the experimental study conducted by Richtner (1986), the size and location of openings through a subject's prosthetic palatal obturator were manipulated and the effect of these openings on speech articulation, resonance quality, and pressure and airflow were measured. Openings of four different sizes (5 mm^2, 10 mm^2, 20 mm^2 and 30 mm^2) were drilled in the removable palatal obturator at four locations - anterior, middle, and posterior part of the hard palate and at the speech bulb, all along the midline. Five perceptual tests (articulation and resonance) were used in this experiment. Nasal airflow, intraoral air pressure, and differential pressure were measured instrumentally. Richtner's findings revealed that hole size and location of the experimental openings (fistulas) determined the degree of speech impairment. Regarding location of the fistula, results from the three instrumental tests and one perceptual test (masked version of the Hypernasality test) showed that the greatest distortions of articulation and resonance quality occurred when the "fistula" was located in the speech bulb. It was also observed that "fistulas" located at the most anterior place of the hard palate (near the incisive foramen) initiate more speech disorders than the other positions among the hard palatal fistulas. That is, palatal openings located posteriorly in the hard palate tended to cause the least disorders of articulation or nasality.

More recently, Hennigsson & Isberg (1987) investigated the influence of open and closed anterior palatal fistulas on speech and resonance in ten adults with repaired cleft palate. Eight of these patients had the fistulas located at the incisive foramen region while two of them had fistulas at the midline of the posterior hard palate. While the fistula was open, hypernasality was present in all ten patients but disappeared with fistula closure in 4 subjects, decreased in 4, and remained unaffected in 2 patients. Weakness of pressure consonants articulated anterior to the fistula was perceived in 8 of the 10 patients when the fistula was open. These patients, however, reported stronger articulation after temporary closure of the fistula. Audible nasal escape during production of pressure sounds articulated anterior to the fistula was observed in 6 patients. After the fistula was closed, audible nasal escape was eliminated in four patients and reduced in the other two. These findings indicated that open-hard palatal fistulas affected the speech of the majority of the patients. Additionally, they suggested that an increasing in velopharyngeal mobility occurred when the anterior fistulas were covered, resulting in an improvement of speech.

The study conducted by Karling, Larson, & Henningsson (1993) investigated the relationship between the location of the fistula (incisive foramen; at the hard palate; and at the junction of the hard and soft palate) and the effects on speech. Two groups of patients were included, 18 with fistulas affecting speech (presence of nasal air emission and hypernasality) and 26 with fistulas not affecting speech. Results from this study showed that there were no differences in the location of the fistula for the two groups (with and without speech problems resulting from fistulas) investigated. That is, the majority of fistulas found for these two groups were located at the foramen incisive or in the hard palate. These authors, therefore, concluded that location of the fistula did not appear to affect the speech outcome. The size of the fistulas, however, was considered to influence speech results. The 18 individuals who had their speech compromised showed larger fistulas than the 26 individuals who did not have their speech affected.

Pinborough-Zimmerman et al. (1997) investigated articulation and nasality changes resulting from sustained palatal fistula obturation in 15 children with palatal fistulas of varied sizes located at three regions: postalveolar/hard palate, postalveolar to incisive foramen, and hard palate. Articulation and nasality were measured when the fistula was open, immediately after obturation, and four to seven weeks postobturation. Acrylic palatal obturators that provided coverage specific to the unique shape and location of each child's fistula were used to achieve fistula obturation. While the fistula was open, nasal air emission and hypernasality were present in all 15 patients and posterior tongue placement errors on sibilant sounds were also perceived. Immediate postobturation resulted in significant improvement on nasal air emission. However, significant improvement in articulation and listener judgments of hypernasality were only observed from the preobturation conditon to four to seven weeks postobturation and from the immediate postobturation condition to four to seven weeks postobturation. That is, significant changes in articulation and nasality between preobturation and immediate postobturation were not observed. The authors, therefore, suggested sustained obturation of anterior fistula prior to the formulation of surgical and speech intervention plans.

Palatal Fistulas and Place of Articulation

Most of the literature investigating the effects of palatal fistula location on speech focused on the description of speech disorders as related to the presence of hypernasality, nasal air emission, and weak pressure consonants. Few authors, however, reported the effects of location of palatal fistulas on place of articulation (Cosman & Falk, 1980; Golding-Kushner, 1995; Hoch et al., 1986; Pinborough-Zimmerman, 1997; Shelton & Blank, 1984; Trost-Cardamone, 1990; Witzel, 1995).

The study conducted by Cosman & Falk (1980) showed that anterior located oronasal fistulas resulted in difficulty for the production of pressure consonants that were produced anteriorly to, or at the locus of the opening. The authors commented that in an effort to compensate for the palatal opening, the place of articulation was sacrificed while the manner of articulation was preserved. As a result, the speaker articulated anterior sounds more posteriorly, that is, behind the place of opening. This same change in place of articulation was identified and described radiographically by Trost (1981), who named this sound deviation as middorsum palatal stop. Several other authors also reported the presence of middorsum palatal stops associated with presence of anterior palatal fistulas (Hoch et al., 1986; Golding-Kushner, 1995; Witzel, 1995).

The effects of location of palatal fistula on place of articulation were also shown in the study conducted by Shelton & Blank (1984). These authors found articulation errors in speech produced by patients who had open palatal fistulas located at the hard palate. These speech errors, however, were not clearly described by these authors. Shelton & Blank merely indicated presence of articulation errors for two out of six patients, with one showing posterior place of articulation. More recently, Trost-Cardamone (1990) stated that palatal fistulas, which are commonly located at the incisive foramen, typically influence pressure consonants produced with linguapalatal constrictions that are anterior to the opening (e.g., /t/, /d/, /s/, z/). Small posterior fistulas, on the other hand, were reported by the author to influence /k/ and /g/ sounds.

Two other studies investigating the influence of "fistulas" on speech did not find any change in place of articulation as related to the presence of fistulas located at the hard and soft palate (Richtner, 1986; Henningsson & Isberg, 1987). In the study conducted by Richtner (1986), no significant differences among the four locations (anterior, middle, and posterior place at the hard palate and soft palate) of the experimental "fistulas" were found for the two articulation tests used. That is, both the Bzoch Error Pattern Screening Articulation Test – BEPSAT – (Bzoch, 1979), which was used to identify complete articulatory proficiency versus no proficiency, and the perceptual rating of articulatory proficiency test did not show significant differences in the results obtained for the four different locations. No differentiation of error type was determined in Ricthner's study.

In Henningsson & Isberg's (1987) investigation, no posterior displacement of dental pressure consonants was also observed in association with anterior palatal openings. This finding was evidenced perceptually and further confirmed by cineradiographic data of the tongue movements during speech production of dental pressure consonants. In contrast, Karling, Larson, & Henningsson (1993) found retracted dental articulation produced by four patients with anterior palatal fistulas. These patients, however, were able to produce high-pressure consonants anterior to the fistulas during the speech tasks.

More recently, Pinborough-Zimmerman et al. (1997) found articulation errors in the speech produced by 15 children who had palatal fistulas of varied sizes located at the anterior palate. In this study, posterior tongue placement errors on sibilant sounds were found prior to fistula obturation. Significant improvement in articulation (i.e. subject's use of more anterior tongue placement) was found after four to seven weeks of fistula obturation. No significant articulation change, however, was observed between preobturation and immediate postobturation. Data from this study, therefore, revealed posterior tongue placement in association with anterior palatal fistula and suggested changes in tongue placement as a result of sustained palatal fistula obturation.

As reported above, there is still a lack of conclusive information regarding the effects fistula location on speech. Additionally, there is some evidence of variations in speech outcomes as a result of immediate and long-term obturation on the anterior fistulas.

Articulatory errors associated with palatal fistulas

Incorrect tongue placement associated with speech of individuals with palatal fistulas has been reported by several authors, including Golding-Kushner (1995; 2001), Hoch et al. (1986), Trost-Cardamone (1997), and Witzel (1995). These articulation errors – named as compensatory articulations (CAs) – are believed to occur as an attempt by the speaker to achieve the manner requirements for production of high-pressure consonants (Witzel, 1995).

Warren (1986) postulated an aerodynamic explanation for the development of compensatory articulation errors resulting from abnormal oronasal couplings, such as palatal fistulas. According to Warren, these articulation errors may be explained as strategies developed by the speaker for satisfying the requirements of a pressure regulating system. Witzel (1995) notes have summarized Warren's regulating system,

> "[Warren's] theory of regulation control is based on the premise that normal speech results from the airflow and pressure of air, which are directed and controlled by the valves of the vocal tract. The flow and pressure of air through the oral cavity are reduced when the VP valve is inadequate or there is a fistula, causing problems with the formation of oral pressure sounds. In response to this inability to create sufficient airflow and pressure through the mouth or vocal tract, the individual may attempt to produce oral speech sounds by shaping the airflow in the lower vocal tract [in a more pressure effective place], where sufficient airflow and pressure can be generated" (page 140).

Trost (1981) refers to compensatory errors as the result of speaker's attempts to approximate their environment's perceptual-acoustic targets. In agreement with Trost, other authors such as Bzoch (1979, 1997) and Hoch et al. (1986) suggested that compensatory errors represent the child's very early attempts to be intelligible. Phillips & Kent (1984) refer to CAs as "… behaviors that are learned and habituated for production of speech sounds, when due to [an abnormal oronasal coupling], normal productions cannot be achieved" (page 162).

Folkins (1985) has suggested that in the presence of changes in the structure(s) of the vocal tract, the control system for speech may adjust through a learning procedure in order to achieve more appropriate perceptual characteristics. Folkins continues that a speaker with VPI or other structural abnormalities following cleft palate operation (e.g.

palatal fistula) develops motor strategies that permit achievement of perceptually acceptable speech.

Even though the development of CAs associated with abnormal oronasal coupling is still not completely understood, it is widely accepted that learning is a precipitating factor (Bzoch, 1979; 1997, Phillips & Kent, 1984; Golding-Kushner, 1995). As Golding-Kushner (2001) stated, "learning plays as a major role in the development and in the maintenance of the compensatory speech errors" (page 16).

The following section describes the compensatory articulations that are commonly associated with palatal fistulas.

Compensatory articulation associated with palatal fistulas

Speech productions involving contacts between the mid-dorsum area of the tongue and hard palate are the sound substitutions most often associated with the presence of palatal fistulas (Golding-Kushner, 1995, 2001; Witzel, 1995). As Witzel (1995) stated, these sound errors indicate an attempt by the speaker to occlude the fistula in an attempt to create pressure buildup while articulating pressure sounds. These compensatory articulations also indicate an attempt by the speaker to produce sounds posterior to the fistula to avoid loss of air pressure through it (Golding-Kushner, 1995; 2001). Although not as common, the presence of CAs such as pharyngeal stops and pharyngeal fricatives are also reported in association with palatal fistulas (Golding-Kushner, 1995; 2001).

Mid-dorsum palatal stops, the compensatory articulation most often associated with speech of individuals with open palatal fistula, was reported by Trost (1981). The author described these compensations as productions involving contacts between the mid-dorsum area of the tongue and the hard palate, in the approximate place where the glide /j/ would be produced. More specifically, the radiographic studies conducted by Trost revealed a "mid-palatal lingual contact with the tongue tip down" (page 196) during production of this compensatory articulation. Mid-dorsum palatal stops are commonly used to replace the stops sounds /t/, /d/, /k/, and /g/. According to Trost, the phoneme boundaries between /t/ and /k/ as well as /d/ and /g/ are lost during the production of mid-dorsum palatal stops articulatory compensations. As a result, a voiceless mid-dorsum palatal stop is produced equally for both /t/ and /k/, whereas a voiced mid-dorsum palatal stop is produced equally for both /d/ and /k/. Phonemic distinctiveness, therefore, is dependent upon non-segmental cues.

Mid-dorsum palatal fricative is also identified in the presence of open palatal fistula (Hoch et al. 1986; Mc Williams et al., 1990; Witzel, 1995). This sound substitution was described by Witzel (1995) as the sound resulting from the approaching of the mid-dorsum area of the tongue to the hard palate to create frication at the approximate place where the glide /j/ would be produced. Its production indicates an attempt by the speaker to occlude the fistula while articulating fricative sounds (Witzel, 1995). Hoch et al. (1986) considered this substitution secondary only to anterior palatal defects and suggested that it can be corrected with speech therapy most effectively once the anterior fistula is closed. As for fricatives, mid-dorsum palatal affricates are reported to occur in the speech of individuals with open fistula. The production of mid-dorsum palatal fricative indicates an attempt to occlude the fistula, while articulating affricate sounds (Witzel, 1995).

Perceptual Identification of Compensatory Articulations Related to Palatal Fistulas

Studies attempting to investigate listeners' perception of compensatory articulations such as mid-dorsum palatal stops were reported in the literature (Santelmann, Sussman, & Chapman, 1999; Trost 1981). Additionally, the ability of listeners to transcribe these sound substitutions were also investigated (Quinzer, 1997).

Trost (1981) described perceptual and physiological aspects of three types of compensatory articulations: mid-dorsum palatal stop, pharyngeal stop, and posterior nasal fricative. In her study, the speech stimuli were presented in sentential contexts and the listeners were asked to identify the compensatory articulations investigated in an underlined segment of the sentence. Trost (1981) found that speech pathologists (with and without experience in craniofacial disorders) were able to identify the compensatory articulations, including mid-dorsum palatal stops, as a distinct class of sound with 86% accuracy after a one-hour training session.

In a more recent study, using a different methodology, Santelmann, Sussman, & Chapman (1999) examined whether listeners could discriminate mid-dorsum palatal stops from other stops using a two-button "change/no change" procedure. They also investigated how listeners identify palatal stops. The authors found that both listeners with training in general phonetics and naive listeners (no training in general phonetics or practice in listening to disordered speech of individuals with cleft palate) were able to discriminate mid-dorsum palatal stops from alveolar and velar stops. According to the authors, these results confirmed that mid-dorsum palatal stops are a distinct articulation and a distinct class of sounds as previously suggested by Trost (1981). However, the listeners included in the study conducted by Santelmann, Sussman, & Chapman (1999) were not able to identify mid-dorsum palatal stops differently from /t/ and /k/. That is, when asked to rate each sound on a scale ranging from one to eight (with one representing the sound closer to /t/ and eight representing the sound closer to /k/), the listeners were not able to rate mid-dorsum palatal stop somewhere in between /t/ and /k/. Santelmann, Sussman, & Chapman (1999) suggested that listeners were sensitive to the acoustic cues that differentiate mid-dorsum palatal stops from other stops but they might not have used these cues to easily categorize them differently. As the authors explained, the listeners failed to identify mid-dorsum palatal stops "because palatal stops are not a phonemic category in English and because the acoustic cues for these stops overlap those from existing phonemic categories in English" (page 240). The authors further stated that listeners might have assimilated mid-dorsum palatal stops into one or the other of the categories – that is, /t/ or /k/.

As mentioned by Santelmann, Sussman, & Chapman (1999), previous study have indicated that

> "even for typical consonants produced by adults, place of articulation distinction have been most difficult for listeners to correctly identify. The mid-dorsum palatal stop [therefore] presents a more difficult contrast, as it is an atypical place of articulation contrast produced by speakers with cleft palate that overlaps with not one, but two, places of articulation in English" (page 241).

Santelmann, Sussman, & Chapman (1999) also suggested that both lack of training to hear mid-dorsum palatal stops and clinical experience in evaluating speech of individuals with cleft palate might also have influenced the listeners in performing the identification tasks. The authors concluded that considerable training in listening to mid-dorsum palatal stops is necessary for listeners to be able to reliably identify and transcribe them. Therefore, the authors suggested that the incidence of this compensatory articulation might be underestimated in the literature.

Quinzer (1997) examined the ability of experienced and inexperienced speech-language pathologists with management of children with cleft palate to transcribe consonant-vowel-consonant words containing compensatory articulations such as mid-dorsum palatal stops. The words were embedded in a carrier phrase and some of the targets were error free, whereas others contained compensatory articulations or conventional speech sound errors. Judges included in this study were instructed to phonetically transcribe only the target word in this task. They were also required to view the compensatory articulation training videotape developed by Trost-Cardamone (1987) before starting the transcription task. After the transcription task, judge's transcriptions were compared with those provided by Trost-Cardamone. Results of this study indicated a significant difference between experienced and inexperienced listeners in the transcription task. However, even the performance of experienced judges was below what is typically reported for reliability in the literature. The results obtained by Quinzer showed difficulties inherent in the transcription of compensatory articulations, including mid-dorsum palatal stops.

The reported literature indicated that compensatory errors that involve contacts between the mid-dorsum area of the tongue and hard palate are not easily identified and transcribed by listeners who do not have considerable training in listening to these distinct speech sounds. The importance of identifying mid-dorsum palatal stops correctly and obtaining reliability on their transcription is crucial for speech language pathologists – SLP(s) who work with individuals with (repaired) oronasal openings as these professionals will work on improving articulation and intelligibility of these population. Quantitative information of the speech characteristics associated with palatal fistulas can also help SLP(s) to certify the identity of the disordered speech productions resulting from these palatal openings. The following section reports quantitative findings obtained on studies that used instrumental measures to investigate changes in place of articulation as a result of palatal fistulas.

Instrumental Evaluation of Changes in Place of Articulation Resulting from Palatal Fistulas

Quantitative information of changes in place of articulation that are commonly associated with palatal fistulas were reported in the studies conducted by Gibbon & Crampin (2001), Isberg & Henningsson (1987), Michi et al. (1986), Santelmann, Sussman & Chapman (1999), Sussman & Chapman (1995), Trost (1981), Yamashita & Michi (1991).

Trost (1981), for example, provided radiographic descriptions of three types of compensatory articulations used by speakers with cleft palate and velopharyngeal inadequacy: the pharyngeal stop, the middorsum palatal stop, and the posterior nasal fricative. The middorsum palatal stop, which is the most common speech deviation associated with palatal fistulas, was described as being produced with tongue tip retracted and mid-dorsum elevated, resulting, therefore, in a posterior palatal contact during production of tip-alveolar [/t,d/] and back-velar stops [/k,g/]. Cineradiographic data of tongue movements involved in the speech produced by individuals with palatal fistulas was also reported in the investigation conducted by Isberg & Henningsson (1987). Findings obtained in this study, however, did not show a consistent tendency for palatal displacement while the patients produced dental pressure consonants with their fistulas alternately open and temporarily closed.

Mitchi et al. (1986) used eletropalatography (EPG), lateral radiography, and airflow examination to examine two types of misarticulations (palatalized misarticulation and lateral misarticulation) produced by a Japanese child who had repaired cleft palate and who also demonstrated adequate velopharyngeal function for speech. Airflow examination was performed in this study using a cold stainless steel plate, which allowed the investigator to observed the direction of the airflow coming from the subject's mouth). Yamashita & Mitchi (1991) reported the use of EPG and sound spectrography (SG) to describe palatilized misarticulation, lateral misarticulation, and nasopharyngeal misarticulation that were produced by Japanese patients who had repaired cleft palate and who demonstrate adequate velopharyngeal function during speech production. The combined results obtained from these two studies indicated that the three reported misarticulations were associated with a common characteristic pattern of a posterior tongue contact. For palatalized misarticulation, in particular, EPG data indicated lingual-palatal constriction and closure occurring at the posterior border of the hard palate with the air passing along the midline of the tongue. Additionally, airflow examination conducted by Mitchi et al. (1986) showed breath flowing straight over the midline of the tongue during production of palatalized misarticulation. Spectrographic data obtained by Yamashita & Mitchi (1991) revealed that the acoustic characteristics of palatized misarticulations were similar to normal velar sounds rather than normal dental and alveolar sounds. Based on instrumental measures they obtained, Yamashita & Mitchi (1991) speculated that both placement and release of lingual contact for palatalized misarticulations were farther back than usual in the speech of the patients they investigated.

From data reported above, Mitchi et al. (1986) and Yamashita & Mitchi (1991) linked palatalized misarticulations they observed to the mid-dorsum palatal stop described previously by Trost (1981). The authors also noted their subjects used the same articulatory movements to produce palatalized stops and palatal fricatives and affricates.

Two recent studies provided acoustic information related to mid-dorsum palatal stops (Santelmann, Sussman & Chapman, 1999; Sussman & Chapman, 1995). As reported in those studies, the acoustic characteristics found for mid-dorsum palatal stops (longer Voice Onset Time -VOT, higher amplitude burst and aspiration noise, and F2 formant transitions that are midway between those expected for /t/ and /k/) represented cues to differentiate from alveolar and velar stops normally produced.

Gibbon and Crampin (2001) used eletropalatographic and acoustic analysis to investigate middorsum palatal stops produced by an English-speaking adult with repaired cleft palate. Perceptual evaluation of the subject's productions was also obtained by two phonetically trained listeners and confirmed that alveolar and velar targets were produced as middorsum palatal stops. Although the two listeners judged /t/ and /k/ as being homophonous (i.e. both produced as middorsum palatal stops), eletropalatagraphic data revealed that the place of articulation for the middorsum palatal stop produced for /t/ was more anterior than the place of articulation for the middorsum palatal stop produced for /k/. Acoustic data revealed that lateral release of air occurred simultaneously with complete tongue palate contact.

From above, it can be concluded that quantitative information adding in the description of changes in place of articulation that are commonly related to palatal fistulas is still limited. Most of the reported studies have focused on the examination of abnormal lingual-palatal contacts (i.e. such middorsum palatal stop) using eletropalatography. That is, using an artificial palate that contains several electrodes (placed in eight horizontal rows according to well-defined anatomical landmarks) inference about the active articulator during middorsum palatal stop production has been drawn. As Gibbon and Crampin (2001) explained, the eletropalatograph does not record which part of the tongue is contacting the palate. However, records of location and timing of tongue contacts with hard palate have proved to be useful in providing objective articulatory data from speakers with cleft palate. Eletropalatograph, therefore, has supplemented the previous radiographic description of middorsum palatal stops presented by Trost (1981).

Eletropalatograph, however, has been used to instrumentally describe changes in tongue placement such as middorsum palatal stops that are produced by individuals with repaired cleft palate. No reports, however, have been described objectively middorsum palatal stops produced by individuals with palatal fistulas. Additionally, there are presently no reports regarding the investigation of tongue movements that occur in the speech produced by individuals with palatal fistulas using eletromagnetic articulography (EMA). That is, to date no study has used EMA to track tongue movement changes associated with palatal fistulas by attaching sensors in different regions of the tongue. The only studies that have used EMA for examining speech related to clef palate population have focused on investigation of velopharyngeal function during speech (Engelke et al., 1996; Poppelreuter, Engelke & Bruns, 2000). Data obtained from these studies revealed that EMA represent a valuable tool in the diagnosis of velopharyngeal function by providing a better understanding of the physiological and pathological mechanism of velar articulatory movements. As explained by Engelke et al. (1996), the use of alternating magnetic fields does not involve x-ray exposure and frame by frame analysis of cine and video recordings of the velopharyngeal structures and adds information about the superior-inferior and/or anterior-posterior displacement of the velum, which can be helpful for diagnosis purposes. The authors also pointed out that "movement data of points inside and outside the vocal tract can be collected simultaneously with the acoustic signal for adequately long recording sessions" (page 236). As for velopharyngeal function, EMA may represent a valuable tool for clinical and research investigation of tongue movements associated with palatal fistulas. Direct monitoring of tongue movements resulting from palatal fistulas of different sizes and location may provide a better understanding of the physiological aspects involved in the speech mechanism of individuals with palatal fistula. That is, while palatography can provide information regarding the place in acrylic plate in which the tongue makes contact, EMA can provide information regarding the part of the tongue involved in such contact as well as the direction and magnitude of the movement in a bi-dimensional plan.

Statement of the Problem

The Need for this Study

Palatal fistulas are detrimental to normal oral speech production since a hole through the palate may result in an increase of nasal air emission, a decrease of intraoral pressure for production of oral consonants, and an increase of nasal resonance. Abnormal tongue placement during speech has also been reported to occur in the presence of palatal fistulas, compromising the individual's speech intelligibility even more. The review of the literature presented in preceding sections of this chapter emphasizes the fact that the magnitude of speech problems associated with palatal fistulas depends largely on the size and location of the palatal fistulas. This fact has been evidenced by clinical observations of speech articulation and resonance and substantiated by instrumental measures of airflow, intraoral pressure, and nasalance. However, there is little quantitative information available on the impact of fistulas of the hard and soft palate on tongue movements during speech production. Most of the information describing changes in place of articulation related to palatal fistulas has relied on clinical observations. Few studies have focused on the description of lingual-palatal contacts that are commonly associated with palatal fistulas using instrumental measures. Additionally, these studies have investigated only the immediate responses after perturbing the speech system. Only one study (Pinborough-Zimmerman et al., 1997) investigated seech outcome resulting from immediate and sustained palatal fistula obturation. The impact that a sustained perturbation has on tongue movements is still unknown.

With this limited information on palatal fistulas and their influence on place of articulation, there is a need for more quantitative information regarding the effect of fistula size and location on articulatory movements. Knowledge about how different sizes and different location of palatal fistulas might influence tongue movements would contribute further to the understanding of the changes in speech production related to palatal fistula. In addition, knowing how tongue movements change in response to a "fistula" might be helpful in guiding clinical management for individuals with palatal fistulas. For example, if tongue movement were found to be in the direction of the hole after closing the hole, the patient would be instructed to have lingual movements away from the hole. Additionally, knowledge about how the articulatory movements might adjust to a perturbation after experiencing an experimentally controlled opening (i.e.

sustained perturbation) would likely contribute to the understanding of speech motor function as related to palatal fistulas.

The present study is intended to be a step toward identifying tongue movements in the speech produced by an individual wearing an experimental palatal obturator with experimentally controlled openings of different sizes and location. A second purpose of the present study is to understand the effect that an experimental palatal fistula of 20 mm^2 located at the hard palate over time has on tongue movements.

Experimental Questions

The following experimental questions were addressed in this study:

1. Are there differences in tongue movements immediately after experimental palatal "fistulas" of varied sizes and locations have been created?
2. Are there differences in tongue movements after the subject had worn the experimental obturator with the 20 mm^2 anterior "fistula" for five days?

Hypotheses

The null hypotheses for the two experimental questions include in this study are:

1. There will be no significant tongue movement differences after experimental palatal "fistulas" of varied sizes and locations have been created.
2. There will be no significant tongue movement differences after the subject had worn the experimental obturator with the 20 mm^2 anterior "fistula" for five days.

The alternate hypotheses are:

1. There will be a significant change in tongue movement after experimental palatal “fistulas” of varied sizes and locations have been created. The change in tongue movement will be expected to occur in the direction of the experimental palatal “fistula” (anterior or posterior) especially for the largest openings.
2. There will be a significant tongue movement differences after the subject had worn the experimental obturator with the 20 mm^2 anterior “fistula” for five days. This change will be expected to be even greater than that found after immediately creating the “fistula”.

CHAPTER 2
METHODOLOGY

The primary purpose of this single-subject study was to investigate speech articulatory performance following the placement of experimentally controlled openings (experimental fistulas) through an experimental palatal speech bulb obturator (replicate of subject's prosthesis) worn by an adult male with an unrepaired cleft of the hard and soft palate. For this investigation, three different size holes were drilled through the replicate palatal obturator at two locations. Data collected from this study were used to answer questions about the effects of experimental coupling of the oral and nasal cavities on articulatory performance as measured by Eletromagnetic Articulography (EMA).

In addition to the experimental conditions in which different hole sizes were drilled through the experimental obturator, two other conditions (controls) were included: 1) subject wearing the experimental obturator with no holes drilled through it–baseline for the anterior hole conditions, and 2) subject again wearing the experimental obturator with no holes drilled through it–baseline for the posterior hole conditions. To assess the effect of an experimental palatal "fistula" over time on articulatory performance, kinematic measurements were obtained at two different occasions: (a) immediately after drilling a particular hole in the experimental obturator, and (b) after five days in which the subject had worn the experimental obturator with a hole drilled through the obturator.

This chapter reviews the operational definitions used in this study and describes the subject, the experimental palatal obturator and all conditions associated with it, the speech stimuli, the instrumentation, data recording, data management, and data analysis.

Operational Definition of Terms

The term “original palatal obturator” is used in this dissertation in reference to the speech palatal obturator that the subject has used throughout his life for covering his unrepaired cleft palate. “Experimental palatal obturator” refers to a near duplicate of the subject’s original palatal obturator used in this study for manipulation of size and location of the experimental fistulas. “Experimental conditions” refer to the conditions in which the subject is wearing the experimental palatal obturator with different size holes drilled through it at two different locations. “Control conditions” refer to the conditions in which the subject is wearing the experimental palatal obturator with no holes drilled through it (baseline for anterior and posterior holes).

Subject

A 43 year-old adult male with a complete bilateral cleft of the hard and soft palate served as the single-subject in this investigation. Surgical closure of the subject’s lip was performed shortly after he was born with several secondary reconstructive repairs of the lip performed at later ages. The palatal cleft was never surgically repaired. The reason for the lack of surgical correction of the palatal cleft, as reported by the subject, was due to the extensive width of his palatal cleft making successful outcome less likely. Therefore, the use of a palatal obturator was selected as the best approach for the management of his palatal cleft.

At age three, the subject was fitted with a removable palatal obturator that resulted in establishing an effective barrier between the oral and nasal cavities. Today, the subject still successfully wears a removable palatal obturator and his speech (voice, articulation and resonance) is not judged to be abnormal by others in his environment by his report. The subject reported no history of voice problems, laryngeal, respiratory, cardiovascular, or neurologic diseases. He is a nonsmoker and was free of symptoms of allergies or colds on the days of testing. Prior to the testing sessions, the subject received a written and verbal explanation of the procedures used in this investigation. He also read and signed the Informed Consent Form approved by the Institutional Review Board at the University of Florida.

Experimental Palatal Obturator

To create controlled openings through the palatal obturator, the subject requested that a replicate of his palatal obturator be constructed for this study. An approximation of the subject's original obturator was constructed and used for this study. The experimental obturator (Figure 2-1) consists of a metal frame and an acrylic resin portion fitting the cleft area. The purpose of the metal frame, which fits the contour of the individual's dental arch, is to retain the obturator firmly in position (Rosen and Bzoch, 1997). This retaining portion of the obturator is clasped on four teeth, the right and left first molars and the right and left canines. The acrylic resin portion of the obturator extends from the metal frame portion and function as an obturator, closing and sealing the cleft in the hard and soft palate.

The subject was required to wear the experimental obturator for two weeks prior to the initiation of data collection involving the experimental obturator in order to adapt to any variances between this obturator and his original one. Previous studies in which this subject participated showed that this period of time was sufficient for him to adjust to this experimental obturator (Richtner, 1986; Sapienza et al., 1996).

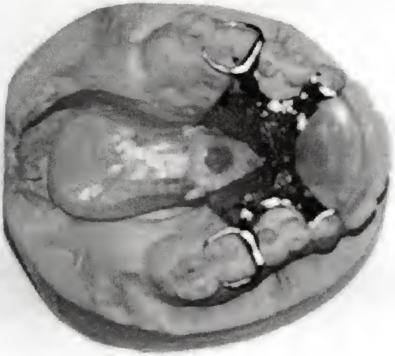


Figure 2-1. Experimental Obturator with the Metal Frame and the Acrylic Resin Portion Fitting the Cleft Area

The decision about the efficiency of the experimental obturator in replicating the subject's original obturator was based in part on the subject's expression of satisfaction while wearing the experimental obturator in terms of accommodation as well as on his speech results. After two weeks, the subject expressed satisfaction with his overall speech while wearing the experimental obturator. Although the subject reported that the experimental obturator did not feel as comfortable as his original obturator, especially at the place of the speech bulb, he was able to wear the experimental obturator without significant discomfort with no implications to his speech.

In addition to the subject's satisfaction with the experimental obturator, two SLP(s) independently perceptually evaluated his speech produced with each obturator (original and experimental). These two judges were experienced in ratings speech disorders associated with VPI. The judges were blinded to the palatal condition (original or experimental obturator) at the time of the speech perceptual assessment. Standardized clinical tests for assessing nasal air emission and nasality (Bzoch, 1997) were obtained while the subject wore each of the two obturators (original and experimental). Conversational speech samples were also used to evaluate his overall speech intelligibility. After evaluating the subject's speech, the two SLP(s) stated that when the subject was wearing the experimental obturator his speech was not perceived as different than speech samples he produced while wearing his original palatal obturator.

Conditions

For this study speech samples were obtained under several conditions. Six experimental conditions involved coupling of the oral and nasal cavities by drilling three size holes through the experimental obturator at two different locations. In addition to the above conditions involving experimental fistulas, data was also recorded while the (1) subject was wearing the experimental obturator with no holes drilled through it–baseline for the anterior hole conditions; and (2) subject was again wearing the experimental obturator with no holes drilled through it–baseline for the posterior hole conditions. Speech samples also were recorded after the subject had worn the experimental obturator for five days with the 20 mm^2 hole in the position approximating the mid point of where the hard palate would be had he not had a palatal cleft. This condition was included in this study in order to investigate the effects of an "experimental fistula" over time on speech. In summary, speech samples were obtained over a total of 9 conditions (Appendix A). Following is a detail of these conditions.

Experimental Conditions

To investigate the effect of size and location of experimentally controlled openings through the obturator on articulatory performance, holes were drilled through the experimental obturator. The subject's speech was then recorded immediately after each hole was drilled in the experimental obturator.

To investigate the effect of location of experimentally controlled openings through the obturator on articulatory performance, openings were positioned in two different locations. Location A was in the midline of A-P axis, halfway between the estimated point of the incisive foramen and the estimated point of the posterior margin of what constitutes the hard palate. Location P was in the midline of the A-P axis, 7 mm anterior of the posterior border of the obturator (Figure 2-2). The distance between the A and P was 30 mm. These two locations were selected based on previous research (Richtner, 1986) which indicated that greatest distortion in speech was perceived when artificial openings were located in the speech bulb (posterior portion of an experimental obturator) and near the point of where the incisive foramen would be located. Additionally, clinical experience has indicated that fistulas occurring as a result of surgical procedures for closing the palatal cleft are usually located at the anterior place of the hard palate (Bardach & Salyer, 1990; Henningsson and Isberg, 1990; Lindsay, 1980; McWilliams, Morris, & Shelton, 1990) or at the junction of the hard and soft palate (Bardach & Salyer, 1990; Henningsson and Isberg, 1990). Although it is recognized that fistulas in the soft palate occur much less frequently than fistulas in the hard palate (Lindsay, 1980), these soft palate fistulas when present also result in significant speech problems for the individual (Henningsson & Isberg, 1990). The experimental opening in which a hole(s) was drilled through the posterior part of the prosthesis was an attempt to mimic the clinical condition of a fistula through the soft palate.

To investigate the effect of size (area) of experimentally controlled openings through the obturator on articulatory performance, holes of three different sizes were drilled through the obturator. Using a standard shop drill press, bits with area sizes of 10 mm^2, 20 mm^2, and 30 mm^2 were used to drill the different holes. These three hole sizes were selected based on earlier research involving artificially induced openings, which revealed consistent negative effects of these three palatal openings on speech production, with greater effects occurring with increased openings (Richtner, 1986; Sapienza et al., 1996). Additionally, clinical experience and qualitative descriptions of clinical cases have also implied speech outcome differences as related to the size of the fistulas, with greater sizes affecting speech more negatively (Shelton & Blank, 1984).

In summary, there were six experimental conditions involving holes of three area sizes at two different locations. The smallest hole (10mm^2) was drilled first, followed by

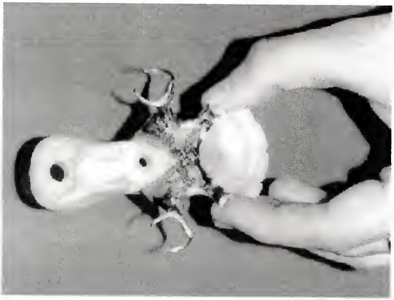


Figure 2-2. Experimental Obturator with Anterior and Posterior Holes

the 20 mm^2 size, and then the 30 mm^2 size. These six experimental conditions were labeled in this study as 10A, 20A, 30A (for the three hole sizes at the anterior location) and 10P, 20P, 30P (for the three hole sizes at the posterior location).

Recordings were obtained in one day with the opening at the anterior location (A) and in the next day with the openings at the posterior location (P). After recording the subject's speech samples for all conditions involving anterior holes the subject was sent home with the experimental obturator with the holes sealed with a resin liquid (Methyl methacrylate).

Control Conditions

Speech recordings were obtained under two control conditions. These control conditions involved recording the subject's speech while he wore the experimental obturator. As reported earlier in this section, baseline recordings with the experimental obturator were performed twice: once before drilling anterior openings through the experimental obturator (EO–A) and once before drilling posterior openings through the experimental obturator (EO–P). Speech samples for EO-A were obtained the same day that the samples with the anterior experimental openings (10A, 20A, 30A) were recorded. Speech samples for EO-P were obtained the same day that the samples with the posterior experimental openings (10P, 20P, 30P) were recorded.

Effects of Experiencing an Experimental Palatal "Fistula" for Five Days

To investigate the effects that an experimental palatal "fistula" might have on speech over time, the subject agreed to wear his experimental obturator with a 20 mm^2 hole in the anterior location for five consecutive days. At the beginning of the sixth day, speech recordings were then obtained while the speaker was still wearing the obturator with the 20 mm^2 openings at the anterior location (condition 20A-5). Because of the functional compromise on speech production resulting from a coupling between oral and nasal cavities due to openings created in the experimental obturator, only one size opening was selected for this part of the investigation. The opening of 20 mm^2 located anteriorly at the experimental obturator was selected because previous findings have indicated that this particular experimental opening results in a substantial negative impact on speech (Richtner, 1986). In choosing five days as the length of time for the subject to wear the experimental obturator with an anterior opening this investigator took into consideration data presented on a previous study by Hamlet and Stone (1976). Hamlet and Stone described a series of experiments in which they observed temporary interference with habitual articulatory patterns as a result of the use of different types of experimental dental prostheses. The authors described articulatory changes immediately after introduction of the prostheses and also changes after the subjects wore the prostheses for a week. In addition, for this study, five days was the maximum period of time that the subject was willing to wear the experimental obturator.

Speech Stimuli

Two groups of speech stimuli were used in this study. The first group consisted of consonant-vowel-consonant (CVC) minimal pairs, where the initial consonant sound was the plosive /t/ or /k/, followed by the vowel /æ/ and the final plosive sound /p/. The second group was consisted of consonant-vowel-consonant (CVC) minimal pairs, where the initial consonant sound was the plosive /p/, followed by the vowel /æ/ and the final plosive sound /t/ or /k/. There were in total four combinations of CVC syllables (tap, pat, cap, and pack). When repeated by the subject, the CVC syllables were embedded in the carrier phrase “Say ___again ”. The CVC syllables were presented in a random order for each of the 9 conditions and for each of the 10 trials within each condition.

The target words “tap, pat, cap, and pack” in the two pairs of CVC syllables were of interest because both initial and final position /t/ and /k/ are often compromised in the presence of fistulas associated with cleft palate (Golding-Kushner, 1995, 2001; Trost, 1981; Witzel, 1995). The plosive /p/ was selected as the constant phoneme in the two minimal pairs because this bilabial sound does not involve tongue movement that would likely interfere with the articulation of the target sounds /t/ and /k/. The adjacent vowel height /æ/ was maintained constant to control for any influence of the tongue height over the target sounds. The carrier phrase was used to ensure the same phonological context surrounded each of the target words.

Instrumentation

For this study an Eletromagnetic Articulograph (EMA), AG-100 (Carstens Medizinelektronik, Germany) was used to record the subject’s tongue movements during speech production. Acoustic signals were recorded simultaneously with the kinematic data and stored in the computer.

The Articulograph

EMA consists of several components, including: a) head helmet with three transmitter coils; b) five small receiver sensors affixed to the subject’s articulators; c) a pre-amplifier to amplify the signal voltage; d) an analog unit connected to the transmitters and sensors; e) the audio box that captures the acoustic signal, f) acoustic and computer interfaces and, g) the calibration system.

Helmet and sensors

The head helmet supports the three-transmitter coils that generate an alternating magnetic field. The position of the three transmitters on a helmet (facing the frontal bone, facing the mandible frontally and, behind the occipital bone) forms an equilateral triangle whose sides limit the measurement field. As in a transformer, the alternating magnetic fields from the transmitters induce alternating voltages in the transducer coils (receive sensors), which are attached to the subject's articulators. As the receiver sensors move through the alternating magnetic fields, small voltages are induced. The voltage induced in each receiver sensor is inversely proportional to the cube of its distance from the transmitter. That is, as the articulators move, the voltage induced in the sensors varies as a consequence of their distance from each transmitter coil. Since the transmitter coils are driven at different frequencies in overlapping magnetic fields, the system is able to obtain, simultaneously, the distances between each sensor and the three transmitter coils.

Pre- amplifier

A pre-amplifier is used in the Articulograph system to amplify the sensor's signal voltage. An analog unit supplies the transmitters on the helmet with the measurement voltages as well as processes the voltage signals of the receiver sensors that are connected to this unit by fine wires. The analog unit converts the induced high frequency signals to three slowly varying output signals from each transducer. These signals are then digitized, along with the speech signal.

Computer interface

The computer interface of the articulatograph allows for digitization of the movement signals captured by the sensors. Once digitized the movement signal can be graphically displayed as midsagital movement curves with anterior-posterior displacement for each specific sensor presented on the X coordinate and superior-inferior displacement from each specific sensor displayed on the Y coordinate. Movement tracing of displacement of the articulator are displayed bi-dimentionally on the computer screen in real-time. The articulograph system comes with operating and analysis software programs to be utilized with personal computers allowing the user to store, edit, measure, and analyze the movement data as well as to print or even export the data to other compatible computer programs.

Audio box

The articulograph audio box captures acoustic data simultaneously with the kinematic data. The acoustic signal can be displayed on the monitor as a wave-form along with the movement curves allowing for play back, and data editing. For this study, the acoustic data signals were obtained by placing a microphone on the subject's tie. This microphone, which was connected to the audio box of the Articulograph, was placed approximately 6 inches from the subject's mouth. Acoustic data obtained by this microphone were sampled at 16 kHz and recorded direct-to-disk for subsequent display along with kinematic data.

Articulograph calibration system

Before running an experiment, a calibration of the system is necessary to assess the accuracy of the measurements. By using the articulograph's calibration system, it is possible to obtain exponents that characterize how the field strengths change with distance from the transmitters (Perkell et al., 1993). Data are generated, for the field calibrations, by inserting each sensor in its respective place in the calibration system. For this study, the Articulograph system was calibrated daily before starting the sessions following manufacturer instructions (Carstens, 1997). Maximum error was 0.5 mm for all recording sessions. This represents a system error no greater than 5% (relative to the sensors being 1cm apart during calibration).

Data Recording

Speaker's Preparation for Data Recording

For this study five small receiver coils (2.2 mm high x 2.5 mm wide x 3.2 mm long and weight 60 mg) were attached, one by one, to the subject's articulators. A biocompatible glue (CYANO-VENEER Fast), designed for use on surface epithelium and mucosal tissue, was used to fix each sensor to the articulators (tongue, lip, and mandible). All sensors were placed on the midsagittal plane. First, a receiver coil was placed on the lower lip at the vermilion border. Second, another coil was affixed to the labiomental groove of the lower jaw. Following that, three other sensors were placed on the tongue surface, in the area of the sulcus medianus.

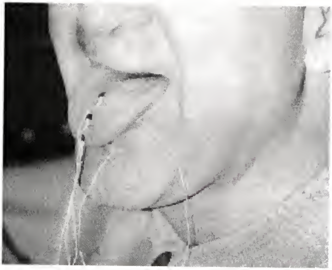


Figure 2-3. Five Receiver Coils Attached to the Subject's Articulator

One of them was placed approximately at the tip of the tongue while the other two were placed approximately 10 and 20 mm distance dorsal to it, that is, at the tongue blade and mid-tongue (Figure 2-3). After assuring the centralized position of the sensors on the subject's articulators, a helmet containing three-eletromagnetic transmitter coils (generator coils) was positioned over the subject's head. The helmet was positioned vertically and horizontally with the center of the measurement plane coinciding with the subject's oral cavity (midsagittal plane).

Receiver coils placed on the tongue tip and tongue body allowed recordings of the subject's tongue movements while receiver coils placed on the lower lip and jaw allowed recording of the subject's lower lip and jaw movements, respectively. During recording all receiver coils were connected to the articulograph unit by means of fine wires led from the corner of the subject's mouth. All these recording were obtained with the subject seated comfortably during all experimental conditions. The subject was not aware of any research questions or conditions being tested during recordings. Even though data was obtained from all five sensors only data recorded from the tongue tip and tongue medium positions were analyzed and will be presented in this study.

Speech Task

With the sensors in place and once positioned under the helmet, the subject was asked to produce ten trials of each target word embedded in the carrier phrase "Say ___again". For this the subject was asked to read the randomized stimuli while the investigator perceptually monitored rate, loudness, and prosody. The subject was instructed to speak in his usual conversational pitch and loudness at a rate of approximately 1 phrase per 2–3 seconds. Unacceptable or inaccurate phrase productions were eliminated and recorded again. The subject was allowed to practice as many times and as long as necessary for achievement of successful production. All speech samples were obtained in a quiet environment at the Speech Motor control Laboratory of the Institute for the Advanced Study of the Communication Processes at the University of Florida.

Signal Monitoring

Two investigators monitored all articulator movements during data recordings. One investigator checked the graphic display of the computer screen for changes that might indicate loosening of an attachment or excessive misalignment of sensors. Movement tracings of each sensor were graphically represented in the screen (by X and Y coordinates) with different colors (blue for lower lip, green for jaw, light blue for tongue tip, red for tongue blade, and purple for tongue medium). Therefore, it was possible to monitor changes for each particular sensor during all recordings.

A second investigator checked the receiver coils by observing the subject's mouth between tasks assuring that the sensors remained in place and that the subject continued to be aligned within the helmet. Additionally, the subject himself was instructed to monitor changes or loses of the sensors from his articulators during the data recording. When a sensor got loosened, the experiment was interrupted. The sensors were glued again at the same place and speech samples were then re-recorded. Recordings with excessive misalignment were excluded from this study. In all cases, no less than 8 repetitions of any target word were recorded.

Kinematic Data Management

Two Windows-based programs were used to perform the Articulograph's signal processing: a) Emalyse, which allows the visualization, analysis, and segmentation of the data, and b) Tailor, which provides signal processing and editing (Cartens, 1997). By using the Tailor tool, the speech samples recorded for each experimental condition were initially down sampled from 500 Hz to 250 Hz and smoothed at 50 Hz for the lower lip and jaw channels and at 80 Hz for all tongue position channels. Emalyse provided the kinematic and acoustic visualization of the processed speech samples for each trial and each condition. After visualizing and also hearing the recorded tokens of each experimental condition, the target word of each trial was selected by positioning cut markers at the beginning and ending of this word. This procedure was repeated until all ten trials for each target word in each experimental condition were selected, marked, and stored in disk.

Data Measurement

Tongue displacement measurements were of interest in this study. Stored speech signals for 10 trials of 4 stimuli produced in 9 conditions were displayed on the computer screen one at a time to extract tongue movement data.

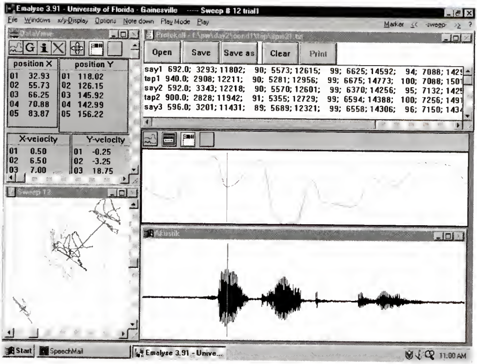
As described earlier, the displacement of two other articulators (jaw and lower lip) were also simultaneously recorded with tongue movements. Because jaw movement data was easier to identify graphically on the screen, especially when the Y coordinate (superior-inferior plane) was displayed, jaw data was selected for directing extraction of tongue trajectory movements during this study.

With the target speech signal, the jaw signals in the superior-inferior plane (S-I) were displayed. Vertical cursors were used to mark the initial and final position of the signal to be measured. The first mark related to the lowest position of the jaw curve for the diphthong /aɪ/ in the word "Say" while the second mark related to the highest position of the jaw curve for the target consonant (/t/ and /k/ for the initial and final position) (Figure 2-4 and 2-5).

After selecting the desired trajectory movement, as identified by jaw data, tongue movement data were extracted. The computer software (Emalyse) automatically generated the corresponding tongue trajectory at the X and Y coordinators. These trajectories were numerically expressed in millimeters (mm).

Tongue-movement analysis

For this study, only anterior-posterior (A-P) tongue movements, that is, front to back or back to front movements represented by X coordinator, were analyzed. Tongue tip (TT) and tongue medium (TM) movements were of interest. Therefore, A-P TT and TM movements for 10 trials of 4 words for all 9 conditions were obtained in this study. There were approximately 180 measurements for each word. That is, 90 measurements for TT and 90 measurements for TM. Although missing values occurred, at lest 8 trials were obtained for TT and TM for each word analyzed.


Emalyse 3.91 - University of Florida - Gainesville ----- Sweep # 12 trial1
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Marker << -sweep- >> ?
Open
Save
Save as
Clear
Print
Start
SpeechMail
Emalyse 3.91 - Unive...
11:00 AM

position X		position Y	
01	32.93	01	118.02
02	55.73	02	126.15
03	66.25	03	145.92
04	70.88	04	142.99
05	83.87	05	156.22

X-velocity		Y-velocity	
01	0.50	01	-0.25
02	6.50	02	-3.25
03	7.00	03	18.75

```
say1  692.0;  3293; 11802;   90;  5573; 12615;   99;  6625; 14592;    94;  7088; 142
tap1  940.0;  2908; 12211;   90;  5281; 12956;   99;  6675; 14773;   100;  7088; 1501
say2  592.0;  3343; 12218;   90;  5570; 12601;   99;  6370; 14256;    95;  7132; 142
tap2  900.0;  2828; 11942;   91;  5355; 12729;   99;  6594; 14388;   100;  7256; 1491
say3  596.0;  3201; 11431;   89;  5689; 12321;   99;  6558; 14306;    96;  7150; 143
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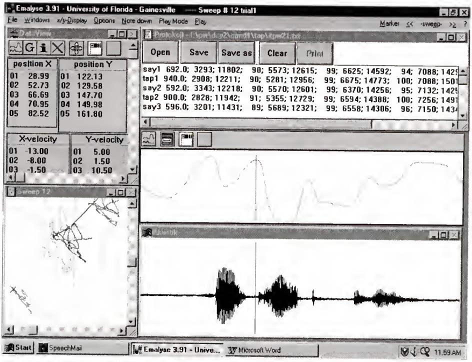
Figure 2-4. Lowest Position of the Jaw Curve for the Diphthong /aɪ/ in the Word "Say".


Emalyse 3.91 - University of Florida - Gainesville ----- Sweep # 12 trial1
File Windows x/y-Display Options Note down Play Mode Play
Marker << -sweep- >> ?
Open
Save
Save as
Clear
Print
Start
SpeechMail
Emalyse 3.91 - Unive...
Microsoft Word
11:59 AM

position X		position Y	
01	28.99	01	122.13
02	52.73	02	129.58
03	66.69	03	147.70
04	70.95	04	149.98
05	82.52	05	161.80

X-velocity		Y-velocity	
01	-13.00	01	5.00
02	-8.00	02	1.50
03	-1.50	03	10.50

```
say1  692.0;  3293; 11802;   90;  5573; 12615;   99;  6625; 14592;    94;  7088; 142
tap1  940.0;  2908; 12211;   90;  5281; 12956;   99;  6675; 14773;   100;  7088; 1501
say2  592.0;  3343; 12218;   90;  5570; 12601;   99;  6370; 14256;    95;  7132; 142
tap2  900.0;  2828; 11942;   91;  5355; 12729;   99;  6594; 14388;   100;  7256; 1491
say3  596.0;  3201; 11431;   89;  5689; 12321;   99;  6558; 14306;    96;  7150; 143
```

Figure 2-5. Highest Position of the Jaw Curve for the Target Consonant.

Tongue movement

To determine whether TT and TM moved anteriorly or posteriorly, numerical measurements obtained from the target consonant (initial or final /t/, initial or final /k/) were subtracted from the /aɪ/ in the word "Say" using Excel Program. The resulting measurements, therefore, represented the A-P movement (in mm) of TT and TM for a particular trial of a target word. The mean and standard deviations of A-P tongue movements were then calculated. Anterior tongue movement (A) was identified by a mean negative values exceeding –0.5 mm. Posterior tongue movement (P) was identified by mean positive values exceeding + 0.5 mm. Given the accuracy of the calibration of the equipment, values between – 0.5 to + 0.5 mm were interpreted as no A-P tongue movement for the target consonant (initial or final /t/, initial or final /k/) relative to the reference diphthong /aɪ/ in the word "Say".

Reliability

To verify reliability of tongue displacement measurements, the investigator repeated the analysis of 36 of 180 (22%) randomly chosen productions. Pearson product-moment correlations were computed to determine the relationship between kinematic measurements obtained by the investigator on the two different occasions. The two measurements demonstrated high agreement on all kinematic measurements. The correlation coefficients were higher than 82% with an average correlation coefficient of 99% for all TT and TM measures (Appendix B).

Data Analysis

The instrumental data collected from this study were analyzed using descriptive and inferential procedures. The mean and standard deviations of A-P tongue movements were obtained to describe TT and TM measurements and identify TT and TM patterns of movement for each target sound produced by the subject under each experimental condition.

Analysis of variance (ANOVA) was used in this study to compare treatment means obtained from the subject's speech production. The statistical analysis was performed using a SAS General Linear Model (GLM) Procedure. Statistical significance was established at $P < 0.05$ for all ANOVA F-tests. TT and TM data were analyzed separately for each target sound investigated.

ANOVA was firstly used to compare means of the control groups. ANOVA was also used to investigate TT and TM of each target consonant under the six experimental conditions (10A, 20A, 30A, 10P, 20P, and 30P) and the two control conditions (EO-A and EO-P). The ANOVA procedure allows for analysis of multiple factors with any number of levels in a single analysis and permits detection of interactions among the various factors (Marks, 1998). The investigation related to the experimental conditions involved two factors that include more than one level to be analyzed. That is, there were two levels of "fistula" location (anterior and posterior) and four levels of size (replicate occluded obturator, 10 mm^2, 20 mm^2, and 30 mm^2) to be analyzed, totaling eight combinations of the two factors of interest (2 x 4). Ten observations were obtained under factor level combination for a total of 80 (2 x 4 x 10) observations for each target sound (4). In some cases, however, missing data occurred but at least eight observations were always obtained under factor level combination. In these cases of two factors (two-way factorial treatment design), the interaction term was always included in the model. The advantage of a factorial design lies in its ability to test whether the effect of one factor depends on the level of the other factor (first order interaction). The independent variables, location and size were treated as fixed effects. A total of 28 pairwise comparisons were done for the eight size and location combinations for each target word (initial and final /t/ and /k/) for each tongue movement under investigation, that is, TT or TM. The 28 comparisons were conducted, using a t-test, to see which of the eight means (EO-A, 10A, 20A, 30A, EO-P, 10P, 20P, 30P) were significantly different from each other. A Bonferroni correction for multiple comparisons was used and the means were only considered different if the p-value was less than 0.0018 (alpha=0.05/28).

A paired t-test was used to compare the means obtained immediately after drilling a 20 mm^2 anterior hole through the subject's experimental obturator to the means obtained after the subject had worn the experimental obturator with the same hole (20 mm^2 anterior) for five days.

CHAPTER 3
RESULTS

This single-subject study investigated changes that occur in tongue articulatory performance during speech in the presence of artificially induced openings (two locations and three sizes) through a palatal obturator covering an unrepaired cleft of the hard and soft palate. In addition to the six experimental conditions in which different holes were drilled through the experimental obturator, two other conditions (controls) were included in this study: (1) subject wearing the experimental obturator with no holes drilled through it – baseline for the anterior hole conditions; and (2) subject again wearing the experimental obturator with no holes drilled through it – baseline for the posterior hole conditions.

A secondary purpose of this study was to identify differences in tongue articulatory movement as a result of the subject wearing the experimental obturator with the 20 mm^2 anterior opening over time. To answer this research question, one additional condition was included in this study, the subject wearing the experimental obturator with the 20 mm^2 anterior hole for five days.

Tongue Tip (TT) and Tongue Medium (TM) kinematic data relative to each condition included in this study are reported in this chapter. Results obtained from control conditions are presented first followed by those gathered from experimental conditions as well as from conditions that investigated the effect of an experimental palatal "fistula" over time.

Findings are presented according to each consonant sound investigated and their position in the stimuli (initial /t/, final /t/, initial /k/, and final /k/). For each consonant sound, descriptive data will be presented first followed by the results of the statistical tests.

Control Conditions

TT and TM data for each of the two control conditions (experimental obturator completely occluded for the anterior hole conditions "EO-A" and the experimental obturator completely occluded for the posterior hole conditions "EO-P") according to each consonant sound (initial and final /t/ and /k/) are presented below.

TT Movement

Means, standard deviations, and TT movement for the consonant /t/ in the initial and final position in the words "tap" and "pat" and the consonant /k/ in the initial and final position in the words "cap" and "pack" are shown in Table 3-1 and 3-2, respectively. TT movement for all these consonants is also shown in Figure 3-1.

Table 3-1. Tongue Tip (TT) Movement Direction (MD), Means (M), and Standard Deviations (SD), in mm, for the Consonant /t/ in the Initial and Final Position for the Control Conditions

	/tæp/			/pæt/		
		TT			TT	
	MD	M	SD	MD	M	SD
EO – A	P	2.01	1.05	P	1.14	0.60
EO – P	A	-0.68	0.88	P	1.26	1.13

As shown in Figure 3-1 and Tables 3-1 a posterior TT movement direction was observed for the consonant /t/ in the initial and final position in the words “tap” and “pat” relative to the diphthong /aɪ/ in the word “say”. The only exception was for EO-A condition in initial position in the word “tap” where TT movement direction was anterior relative to the diphthong /aɪ/ in the word “say”. Additionally, TT mean for EO-A condition in initial position in the word “tap” was statistically significant different than TT mean for EO-P condition (p = 0.0001).

Table 3-2. Tongue Tip (TT) Movement Direction (MD), Means (M), and Standard Deviations (SD), in mm, for the Consonant /k/ in the Initial and Final Position for the Control Conditions

	/kæp/			/pæk/		
	TT			TT		
	MD	M	SD	MD	M	SD
EO – A	A	-2.75	0.43	P	1.71	0.99
EO – P	A	-2.54	0.59	P	2.82	1.12

As shown in Figure 3-1 and Table 3-2, for the consonant /k/ in the initial position in the word “cap” an anterior TT movement was observed for both EO-A and EO-P conditions. An analysis of variance did not show significant differences between the EO-A and the EO-P TT means.

As shown in Figure 3-1 and Table 3-2, for the consonant /k/ in the final position in the word “pack” a posterior TT movement was observed for both EO-A and EO-P conditions. An analysis of variance did not show significant differences between the EO-A and the EO-P TT means.

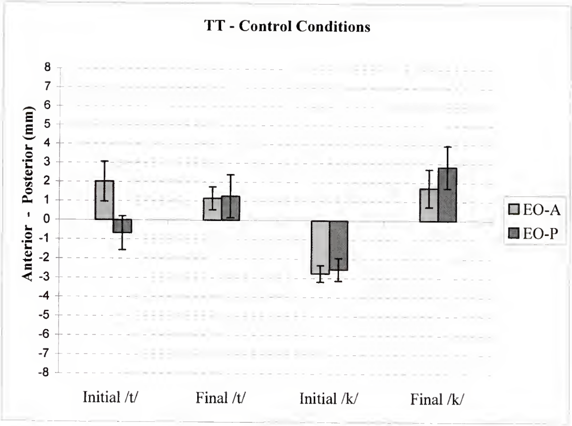


Figure 3-1. Means (mm) and Standard Deviations of Tongue Tip (TT) Movement (Anterior or Posterior) for the Consonants /t/ and /k/ in the Initial and Final Position for the Control Conditions

TM Movement

Means, standard deviations, and TM movement for the consonant /t/ in the initial and final position in the words “tap” and “pat” and the consonant /k/ in the initial and final position in the words “cap” and “pack” are shown in Table 3-3 and 3-4, respectively. TM movement for all these consonants is also shown in Figure 3-2.

Table 3-3. Tongue Medium (TM) Movement Direction (MD), Means (M), and Standard Deviations (SD), in mm, for the Consonant /t/ in the Initial and Final Position for the Control Conditions

	/tæp/			/pæt/		
	TM			TM		
	MD	M	SD	MD	M	SD
EO – A	N	-0.02	1.66	P	3.34	0.99
EO – P	N	0.29	1.05	P	3.41	1.42

As shown in Figure 3-2 and Tables 3-3 no anterior-posterior TM movement was observed for the consonant /t/ in the initial position in the word “tap” relative to the diphthong /aɪ/ in the word “say” for both EO-A and EO-P conditions. A posterior TM movement direction was observed for the consonant /t/ in the final position in the word “pat” relative to the diphthong /aɪ/ in the word “say” for both EO-A and EO-P conditions. An analysis of variance did not show a significant difference between the EO-A and the EO-P TM means.

As shown in Figure 3-2 and Table 3-4, for the consonant /k/ in the initial position in the word “cap” an anterior TM movement relative to the diphthong /aɪ/ in the word "say" was observed for both EO-A and EO-P conditions. An analysis of variance did not show significant difference between the EO-A and EO-P TM means.

As shown in Figure 3-2 and Table 3-4, for the consonant /k/ in the final position in the word "pack" an anterior TM movement relative to the diphthong /aɪ/ in the word "say" was observed for the EO-A condition while no anterior-posterior TM movement was found for the EO-P condition. An analysis of variance showed significant difference between the EO-A and the EO-P TM means (p = 0.0007).

Table 3-4. Tongue Medium (TM) Movement Direction (MD), Means (M), and Standard Deviations (SD), in mm, for the Consonant /k/ in the Initial and Final Position for the Control Conditions

	/kæp/			/pæk/		
	TM			TM		
	MD	M	SD	MD	M	SD
EO – A	A	-3.67	1.58	A	-2.20	1.27
EO – P	A	-4.34	0.61	N	0.01	1.08

In summary, statistically significant differences between EO-A and EO-P means were found for 33% of all data (2/8) obtained for the consonants /t/ and /k/ in both initial and final position.

Further review of the Figure 3-1 showed a posterior TT movement direction for 75% of all data (3/4) obtained for the consonant /t/. That is, relative to the diphthong /aɪ/ in the word "say", TT moved posteriorly most of the time when the consonant /t/ was produced. Additionally, when observed, TM also moved posteriorly for the consonant /t/ relative to the diphthong /aɪ/ in the word "say". These findings, therefore, revealed that,

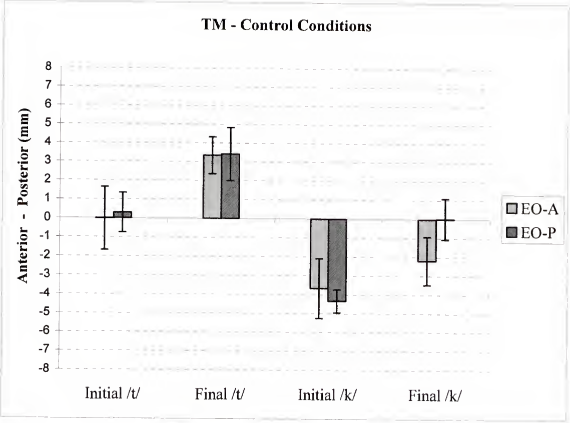


Figure 3-2. Means (mm) and Standard Deviations of Tongue Medium (TM) Movement (Anterior or Posterior) for the Consonants /t/ and /k/ in the Initial and Final Position for the Control Conditions

relative to the diphthong /aɪ/ in the word "say", TT posterior movement was central during production of the consonant /t/. Further review of the Figure 3-2 showed an anterior TM movement direction for 75% of all data (3/4) obtained for the consonant /k/. That is, relative to the diphthong /aɪ/ in the word "say", TM moved anteriorly most of the time when the consonant /k/ was produced. Additionally, TT also moved anteriorly for the consonant /k/ in the initial position relative to the diphthong /aɪ/ in the word "say". These findings, therefore, revealed that, relative to the diphthong /aɪ/ in the word "say", TM anterior movement was central during production of the consonant /k/

Experimental Conditions

TT and TM data for each of the six experimental conditions (three holes at the anterior "10A, 20A, 30A" and posterior "10P, 20P, 30P" place of the experimental obturator) and two control conditions (experimental obturator completely occluded – baseline for the anterior hole conditions "EO-A", and the experimental obturator completely occluded – baseline for the posterior hole conditions "EO-P") according to each consonant sound (initial /t/, final /t/, initial /k/, and final /k/) are presented below. A summary of the TT and TM findings for these experimental conditions is shown in Appendix C.

TT Movement

Means, standard deviations, and TT movement for the consonant /t/ in the initial and final position in the words "tap" and "pat" and for the consonant /k/ in the initial and final position in the words "cap" and "pack" are shown in Table 3-5 and 3-6, respectively. Figures 3-3 – 3-6 show these results graphically by size while Figures 3-7 – 3-10 show these results graphically by location.

Table 3-5. Tongue Tip (TT) Movement Direction (MD), Means (M), and Standard Deviations (SD), in mm, for the Consonant /t/ in the Initial and Final Position for the Six Experimental Conditions and the Two Control Conditions.

	/tæp/			/pæt/		
	TT			TT		
	MD	M	SD	MD	M	SD
EO – A	P	2.01	1.05	P	1.14	0.60
10A	P	2.33	1.12	P	1.88	1.69
20A	P	2.04	1.21	P	3.34	1.40
30A	P	1.33	0.74	P	1.65	2.00
EO – P	A	-0.68	0.88	P	1.26	1.13
10P	A	-0.72	0.87	P	1.41	0.92
20P	A	-1.18	0.43	P	1.90	0.93
30P	A	-2.13	1.13	P	1.34	0.96

As seen in Figure 3-3, for the consonant /t/ in the initial position in the word "tap" a posterior TT movement was observed for all the experimental conditions involving holes drilled anteriorly (10A, 20A, and 30A) as well as for the control condition EO – A. Mean TT movement data relative to the reference diphthong /aɪ/ in the word "say" obtained for these four conditions indicated that greater posterior TT movement was observed for the experimental condition 10 A than was observed for the experimental condition 30A (Table 3-5). Figure 3-3 also shows that an anterior TT movement occurred for all the experimental conditions involving holes drilled posteriorly (10P, 20P, and 30P) as well as for the control condition EO – P. Mean TT movement data relative

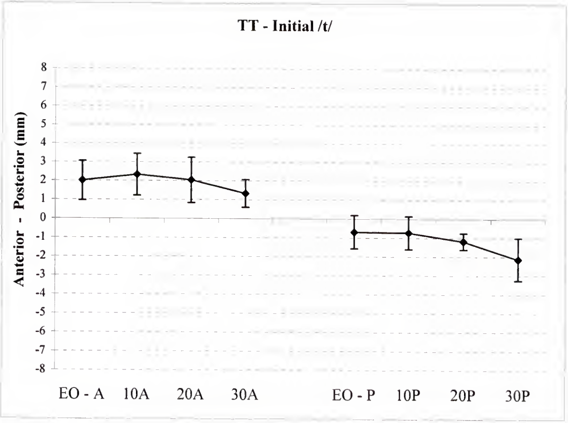


Figure 3-3. Means (mm) and Standard Deviations of Tongue Tip (TT) Movement (Anterior or Posterior) for the Consonant /t/ in the Initial Position for the Six Experimental Conditions and the Two Control Conditions.

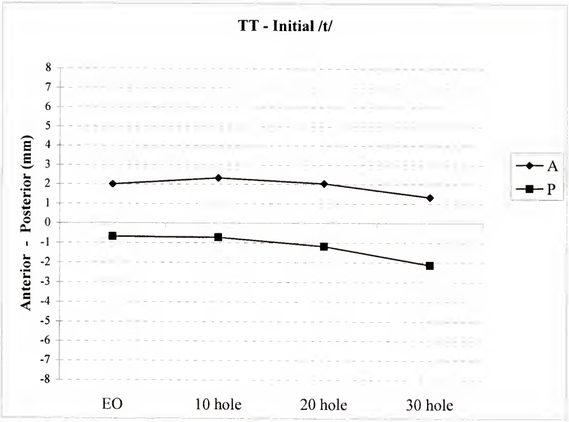


Figure 3-7. Means (mm) of Tongue Tip (TT) Movement (Anterior or Posterior) for the Two Locations (Anterior and Posterior) for the Consonant /t/ in the Initial Position for the Six Experimental Conditions and the Two Control Conditions.

to the reference diphthong /aɪ/ in the word "say" obtained for these four conditions indicated that greater anterior TT movement was observed for the experimental condition 30P than was observed for the conditions 10P and 20P (Table 3-5). An analysis of variance indicated significant differences between the TT means (F = 31.72, df = 7, p = 0.0001). The pairwise comparisons employed to identify differences between the two locations for each size indicated significant differences between each pair of locations (EO-A and EO-P, 10A and 10P, 20A and 20P, and 30A and 30P conditions - Figure 3-7). The pairwise comparisons employed to identify differences among the sizes for each location indicated a significant difference between the baseline condition EO-P and the experimental condition 30P (Figure 3-3).

As seen in Figure 3-4, for the consonant /t/ in the final position in the word "pat" a posterior TT movement was observed for all the experimental conditions involving holes drilled anteriorly (10A, 20A, and 30A) and posteriorly (10P, 20P, and 30P) as well as for the control conditions EO – A and EO-P. Mean TT movement data relative to the reference diphthong /aɪ/ in the word "say" obtained for the four anterior conditions and four posterior conditions indicated that the greatest posterior TT movement was observed for the experimental condition 20 A and 20P (Table 3-5). An analysis of variance indicated significant differences between the TT means (F = 2.99, df = 7, p = 0.0082). The pairwise comparisons employed to identify differences between the two locations for each size did not indicate significant differences between each pair of locations (Figure 3-8). The pairwise comparisons employed to identify differences among the sizes for each location indicated a significant difference only between the baseline condition EO-A and the experimental condition 20A (Figure 3-4).

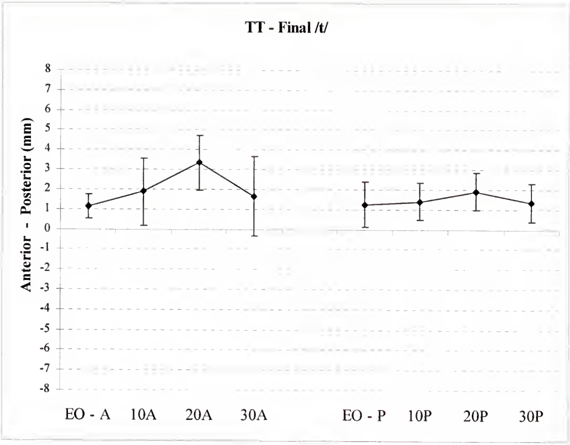


Figure 3-4. Means (mm) and Standard Deviations of Tongue Tip (TT) Movement (Anterior or Posterior) for the Consonant /t/ in the Final Position for the Six Experimental Conditions and the Two Control Conditions.

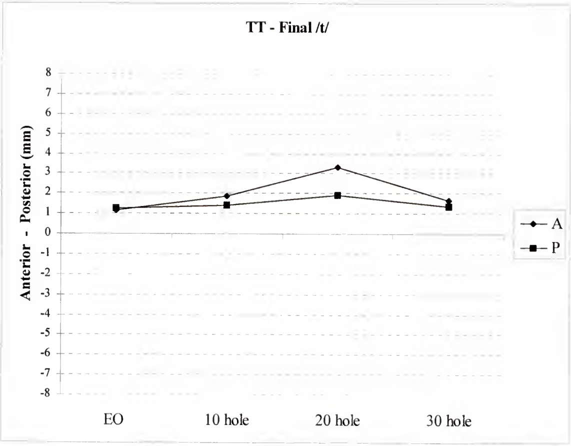


Figure 3-8. Means (mm) of TT Movement (Anterior-Posterior) for the Two Locations (Anterior or Posterior) for the Consonant /t/ in the Final Position for the Six Experimental Conditions and the Two Control Conditions.

As seen in Figure 3-5, for the consonant /k/ in the initial position in the word “c̲ap” an anterior TT movement was observed for all the experimental conditions involving holes drilled anteriorly (10A, 20A, and 30A) and posteriorly (10P, 20P, and 30P) as well as for the control conditions EO–A and EO–P. Mean TT movement data relative to the reference diphthong /aɪ/ in the word “say” obtained for the four anterior and posterior conditions indicated that, compared to their baselines, the greatest anterior TT movement was observed for the experimental conditions 30A and 30P (Table 3-6). An analysis of variance indicated significant differences between the TT means (F = 10.32, df = 7, p = 0.0001). Between the two locations for each size the pairwise comparisons indicated a significant difference between the 20A and 20P locations (Figure 3-9). The pairwise comparisons employed to identify differences between the sizes for each location indicated a significant difference between the conditions EO-A and 20A, EO-A and 30A as well as between 10A and 30A (Figure 3-5).

Table 3-6. Tongue Tip (TT) Movement Direction (MD), Means (M), and Standard Deviations (SD), in mm, for the Consonant /k/ in the Initial and Final Position for the Six Experimental Conditions and the Two Control Conditions.

		/kæp/			/pæk/	
		TT			TT	
	MD	M	SD	MD	M	SD
EO – A	A	-2.75	0.43	P	1.71	0.99
10A	A	-3.49	1.67	N	-0.28	0.75
20A	A	-4.62	0.38	A	-2.03	1.00
30A	A	-5.27	1.95	A	-2.88	1.43
EO – P	A	-2.54	0.59	P	2.82	1.12
10P	A	-2.28	0.56	P	1.03	0.95
20P	A	-2.59	1.00	P	0.87	1.08
30P	A	-3.82	0.68	A	-3.78	2.04

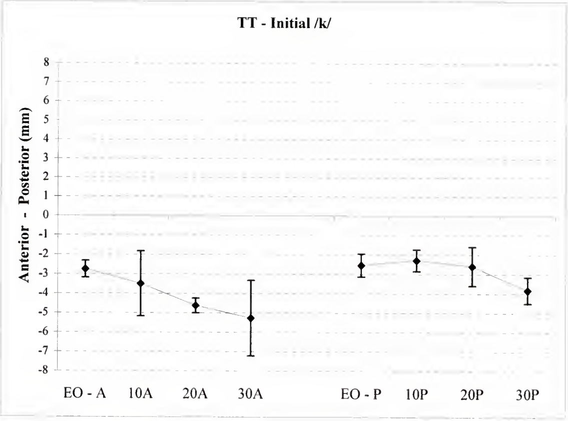


Figure 3-5. Means (mm) and Standard Deviations of Tongue Tip (TT) Movement (Anterior or Posterior) for the Consonant /k/ for the Initial Position for the Six Experimental Conditions and the Two Control Conditions.

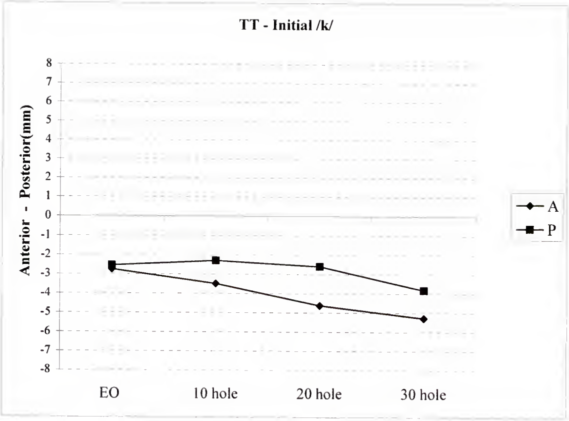


Figure 3-9. Means (mm) of Tongue Tip (TT) Movement (Anterior or Posterior) for the Two Locations (Anterior and Posterior) for the Consonant /k/ in the Initial Position for the Six Experimental Conditions and the Two Control Conditions.

As seen in Figure 3-6, for the consonant /k/ in the final position in the word "pack" there was a trend for greater anterior TT movement for larger hole sizes for both anterior and posterior holes. Mean TT movement data relative to the reference diphthong /aɪ/ in the word "say" obtained for the four anterior conditions indicated that the greatest anterior TT movement was observed for the experimental condition 30 A (Table 3-6). Additionally, as seen in Figure 3-6, posterior TT movement was observed for the conditions EO-P, 10P, and 20P. However, relative to the control condition, TT movement became progressively more anterior with the greatest anterior movement for the 30 P condition. An analysis of variance indicated significant differences between the TT means (F = 24.27, df = 7, p = 0.0001). The pairwise comparisons employed to identify differences between the two locations for each size indicated a significant difference between the 20A and 20P (Figure 3-10). The pairwise comparisons employed to identify differences between the sizes for each location indicated significant differences between the conditions EO-A and 10A, EO-A and 20A, EO-A and 30A, 10A and 30A; EO-P and 20P as well as between EO-P and 30P (Figure 3-6).

Further review of the Figures 3-7 and 3-8 showed that, for the consonant /t/ in the initial and final position in the words "tap" and "pat", a general trend for more posterior TT movement was observed for the experimental conditions in which holes were drilled at the anterior place of the experimental obturator. Figure 3-9 and 3-10 showed that, for the consonant /k/ in the initial and final position in the words "cap" and "pack", a general trend for more anterior TT movement was observed for the experimental conditions in which holes were drilled at the anterior place of the experimental obturator.

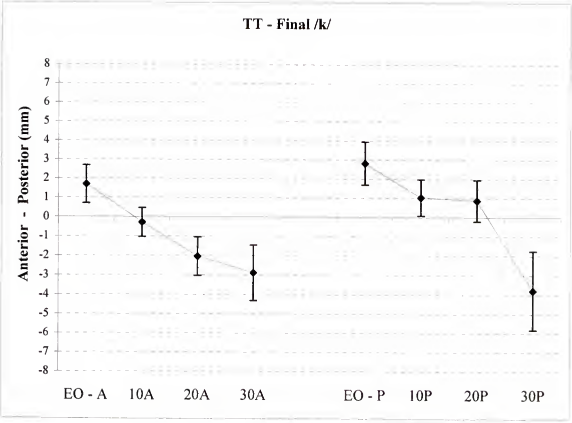


Figure 3-6. Means (mm) and Standard Deviations of Tongue Tip (TT) Movement (Anterior or Posterior) for the Consonant /k/ in the Final Position for the Six Experimental Conditions and the Two Control Conditions.

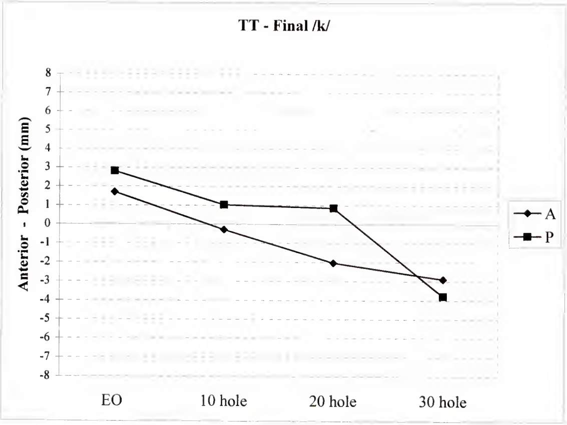


Figure 3-10. Means (mm) of Tongue Tip (TT) Movement (Anterior or Posterior) for the Two Locations (Anterior and Posterior) for the Consonant /k/ in the Final Position for the Six Experimental Conditions and the Two Control Conditions.

Further review of the Figures 3-3 – 3-6 showed that, for the consonant /t/ and /k/ in the initial and final position ("tap", "pat", "cap", an "pack") the largest anterior TT movement was observed for the experimental conditions in which a 30 mm^2 hole was drilled through the experimental obturator. Additionally, for the consonant /t/ and /k/ in the initial and final position ("tap", "pat", "cap", an "pack"), no differences were observed between the baseline and 10 mm^2 holes.

TM Movement

Means, standard deviations, and TM movement for the consonant /t/ in the initial and final position in the words "tap" and "pat" and for the consonant /k/ in the initial and final position in the words "cap" and "pack" are shown in Table 3-7 and 3-8, respectively. Figures 3-11 – 3-14 illustrates these results graphically by size while Figures 3-15 – 3-18 illustrates these results graphically by location.

Table 3-7. Tongue Medium (TM) Movement Direction (MD), Means (M), and Standard Deviations (SD), in mm, for the Consonant /t/ in the Initial and Final Position for the Six Experimental Conditions and the Two Control Conditions.

		/tæp/			/pæt/	
		TM			TM	
	MD	M	SD	MD	M	SD
EO – A	N	-0.02	1.66	P	3.34	0.99
10A	P	0.61	1.26	P	2.06	2.10
20A	P	0.89	0.60	P	2.45	0.65
30A	P	0.56	0.98	N	0.47	1.40
EO – P	N	0.29	1.05	P	3.41	1.42
10P	P	0.89	1.18	P	4.07	0.55
20P	N	-0.19	0.58	P	3.98	1.50
30P	A	-1.84	1.17	P	2.77	1.12

As seen in Figure 3-11, for the consonant /t/ in the initial position in the word “t̲ap” a posterior TM movement was observed for all the experimental conditions involving holes drilled anteriorly (10A, 20A, and 30A). Mean TM movement data relative to the reference diphthong /aɪ/ in the word “say” obtained for these three conditions indicated that greater posterior TM movement was observed for the experimental condition 20 A than was observed for the experimental conditions 10A and 30A (Table 3-7). Additionally, almost no anterior-posterior tongue movement was observed for the control condition EO-A. Figure 3-11 also shows that an anterior TM movement occurred for the experimental condition 10P while an anterior TM was observed for the experimental condition 30P. A trend for posterior TM movement was also observed for the experimental condition 20P while a trend for TM anterior movement was observed for the control condition EO-P. An analysis of variance indicated significant differences between the TM means ($F = 5.99$, $df = 7$, $p = 0.0001$). The pairwise comparisons employed to identify differences between the two locations for each size indicated a significant difference between the experimental conditions 30A and 30P (Figure 3-15). The pairwise comparisons employed to identify differences among the sizes for each location indicated a significant difference between the control condition EO-P and the experimental condition 30P as well as between the experimental conditions 10P and 30P (Figure 3-11).

As seen in Figure 3-12, for the final consonant /t/ in the word “pat̲” a posterior TM movement was observed for all the experimental conditions involving holes drilled anteriorly (10A, 20A, and 30A) as well as for the control condition EO – A. Mean TM movement data relative to the reference diphthong /aɪ/ in the word “say” obtained for these three experimental conditions indicated that slightly greater posterior

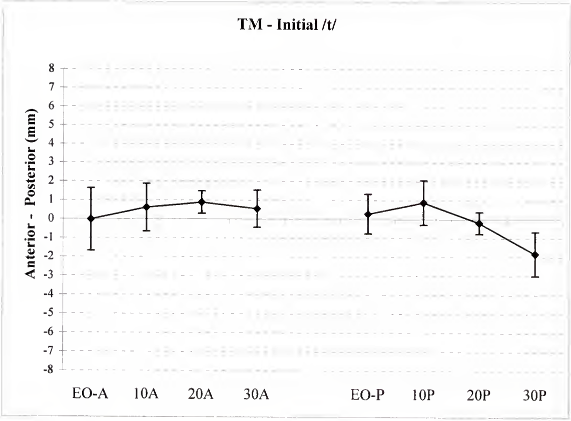


Figure 3-11. Means (mm) and Standard Deviations of Tongue Medium (TM) Movement (Anterior or Posterior) for the Consonant /t/ in the Initial Position for the Six Experimental Conditions and the Two Control Conditions.

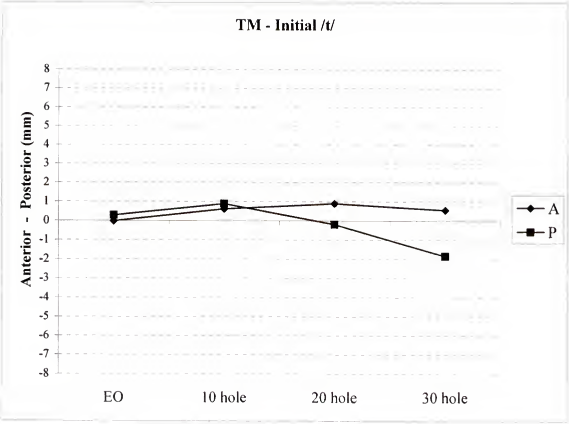


Figure 3-15. Means (mm) of Tongue Medium (TM) Movement (Anterior or Posterior) for the Two Locations (Anterior and Posterior) for the Consonant /t/ in Initial Position for the Six Experimental Conditions and the Two Control Conditions.

TM movement was observed for experimental condition 20A than was observed for the other two experimental conditions.

Figure 3-12 also shows that a posterior TM movement occurred for all the experimental conditions involving holes drilled posteriorly (10P, 20P, and 30P) as well as for the control condition EO – P. Mean TM movement data relative to the reference diphthong /aɪ/ in the word "say" obtained for these four conditions indicated that greater posterior TM movement was observed for the experimental conditions 10P and 20P (Table 3-7). An analysis of variance indicated significant differences between the TM means (F = 8.17, df = 7, p = 0.0001). The pairwise comparisons employed to identify differences between the two locations for each size indicated a significant difference between the experimental conditions 10A and 10P and 30A and 30P (Figure 3-16). The pairwise comparisons employed to identify differences among the sizes for each location indicated a significant difference between the baseline condition EO-A and the experimental condition 30A as well as between the experimental conditions 20A and 30a. (Figure 3-12).

As seen in Figure 3-13, for the consonant /k/ in the initial position in the word "c̲ap" an anterior TM movement was observed for all the experimental conditions involving holes drilled anteriorly (10A, 20A, and 30A) as well as for the control condition EO – A. Mean TM movement data relative to the reference diphthong /aɪ/ in the word "say" obtained for these four conditions indicated that the least anterior TM movement was observed for the experimental condition 30A (Table 3-8).

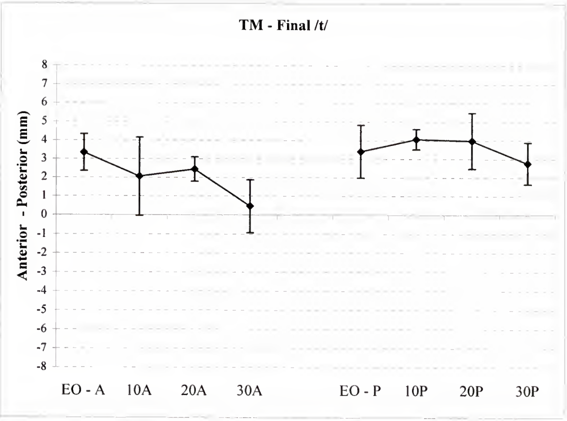


Figure 3-12. Means (mm) and Standard Deviations of Tongue Medium (TM) Movement (Anterior or Posterior) for the Consonant /t/ in the Final Position for the Six Experimental Conditions and the Two Control Conditions.

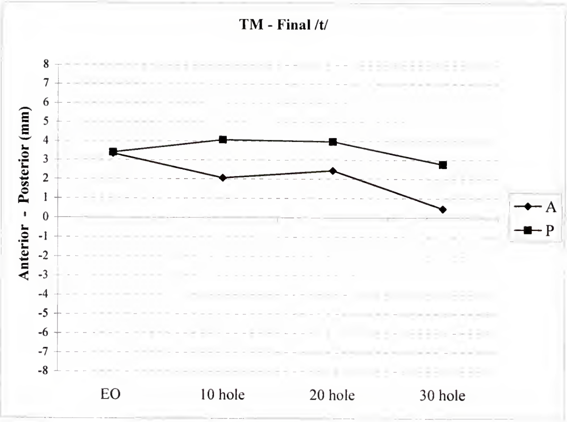


Figure 3-16. Means (mm) of Tongue Medium (TM) Movement (Anterior or Posterior) for the Two Locations (Anterior and Posterior) for the Consonant /t/ in the Final Position for the Six Experimental Conditions and the Two Control Conditions.

Figure 3-13 also shows that an anterior TM movement occurred for all the experimental conditions involving holes drilled posteriorly (10P, 20P, and 30P) as well as for the control condition EO – P (baseline). Mean TM movement data relative to the reference diphthong /aɪ/ in the word "say" obtained for these four conditions indicated that a slightly greater anterior TM movement was observed for the control condition EO-P and the experimental condition 20P than was observed for the other two experimental conditions (Table 3-8). An analysis of variance indicated significant differences between the TM means (F = 24.02, df = 7, p = 0.0001). The pairwise comparisons employed to identify differences between the two locations for each size indicated a significant difference between the experimental conditions 20A and 20P as well as between the experimental conditions 30A and 30P (Figure 3-17). The pairwise comparisons employed to identify differences among the sizes for each location indicated a significant difference between the conditions EO-A and 20A, EO-A and 30A as well as between the experimental conditions 10A and 30A and 10A and 20A (Figure 3-13).

Table 3-8. Tongue Medium (TM) Movement Direction (MD), Means (M), and Standard Deviations (SD), in mm, for the Consonant /k/ in the Initial and Final Position for the Six Experimental Conditions and the Two Control Conditions.

	/kæp/			/pæk/		
		TM			TM	
	MD	M	SD	MD	M	SD
EO – A	A	-3.67	1.58	A	-2.20	1.27
10A	A	-2.63	1.46	A	-2.96	1.45
20A	N	-0.42	0.94	P	1.40	0.86
30A	N	-0.21	1.22	P	2.48	1.86
EO – P	A	-4.34	0.61	N	0.01	1.08
10P	A	-3.86	0.81	A	-1.69	1.26
20P	A	-2.59	1.00	A	-1.99	1.62
30P	A	-3.82	0.68	A	-1.57	1.44

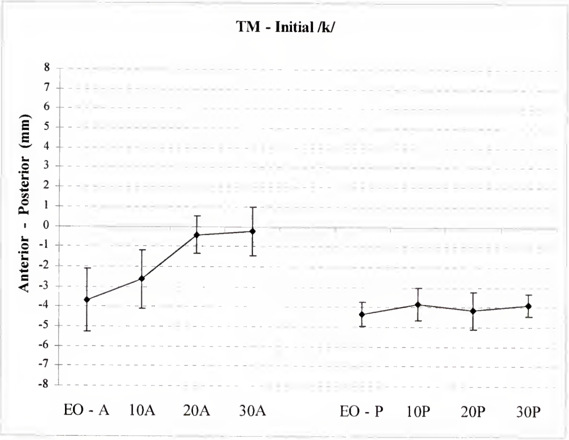


Figure 3-13. Means (mm) and Standard Deviations of Tongue Medium (TM) Movement (Anterior or Posterior) for the Consonant /k/ in the Initial Position for the Six Experimental Conditions and the Two Control Conditions.

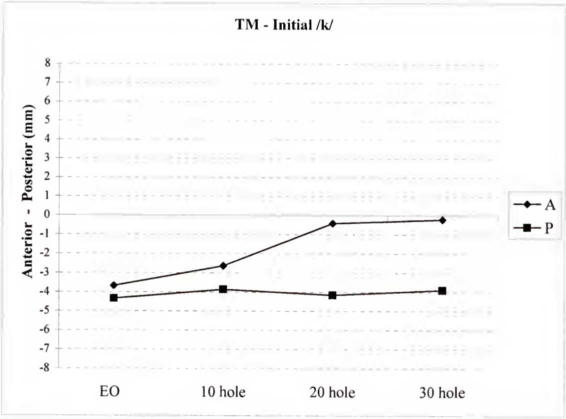


Figure 3-17. Means (mm) of Tongue Medium (TM) Movement (Anterior or Posterior) for the Two Locations (Anterior and Posterior) for the Consonant /k/ in the Initial Position for the Six Experimental Conditions and the Two Control Conditions.

As seen in Figure 3-14, for the consonant /k/ in the final position in the word "pack" a posterior TM movement was observed for the experimental conditions 20A and 30A while an anterior TM movement was observed for the experimental condition 10A and the control condition EO-A. Mean TM movement data relative to the reference diphthong /aɪ/ in the word "say" obtained for these four conditions indicated that greater posterior TM movement was observed for the experimental condition 30A while greater anterior TM movement was observed for the experimental condition 10A (Table 3-8). Additionally, as seen in the Figure 3-14, an anterior TM was observed for the experimental conditions 10P, 20P, and 30P while no anterior –posterior movement was identifiable for the baseline condition EO-P. Mean TM movement data relative to the reference diphthong /aɪ/ in the word "say" obtained for these four conditions indicated that the greatest anterior TM movement was observed for the experimental condition 20P (Table 3-8). An analysis of variance indicated significant differences between the TM means ($F = 18.98$, $df = 7$, $p = 0.0001$). The pairwise comparisons employed to identify differences between the two locations for each size indicated a significant difference between the experimental conditions 20A and 20P, 30A and 30P as well as between the control condition EO-A and EO-P (Figure 3-18). The pairwise comparisons employed to identify differences among the sizes for each location indicated a significant difference between the conditions EO-A and 20A, EO-A and 30A as well as between the experimental conditions 10A and 20A and 10A and 30A (Figure 3-14).

Further review of the Figures 3-15 – 3-18 showed that, for the consonant /k/ in the initial and final position in the words "cap" and "pack" and for the consonant /t/ in the final position in the word "pat", a general trend for more posterior TM movement was

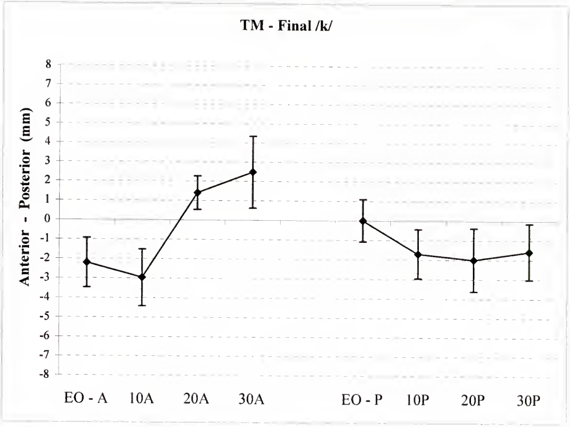


Figure 3-14. Means (mm) and Standard Deviations of Tongue Medium (TM) Movement (Anterior or Posterior) for the Consonant /k/ in the Final Position for the Six Experimental Conditions and the Two Control Conditions.

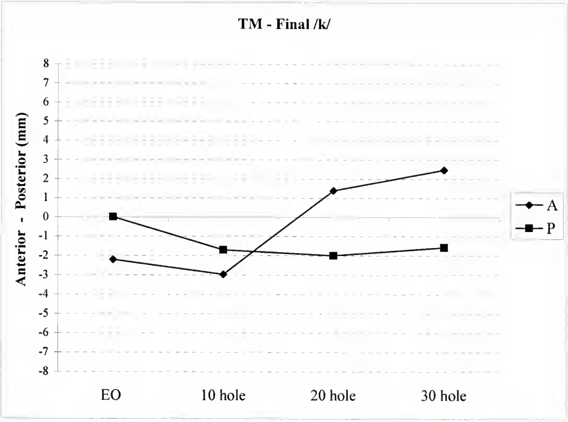


Figure 3-18. Means (mm) of Tongue Medium (TM) Movement (Anterior or Posterior) for the Two Locations (Anterior and Posterior) for the Consonant /k/ in the Final Position for the Six Experimental Conditions and the Two Control Conditions.

observed for the experimental conditions in which holes were drilled at the anterior place of the experimental obturator.

Further review of the Figures 3-11 – 3-14 showed that, for the consonant /t/ in the initial position in the word "tap", the largest anterior TM movement was observed for the experimental conditions in which a 30 mm^2 hole was drilled through the experimental obturator. For the consonant /t/ in the final position in the word "pat", the largest posterior TM movement was observed for the 10P and 20P conditions. For the consonant /k/ in the initial and final position in the words "cap" and "pack", the only posterior TM movement observed was for 20A and 30A conditions.

Effects of Experiencing an Experimental "Fistula" for Five Days

TT and TM data for the condition with the 20 mm^2 anterior hole over time (20A-5), the condition with the 20 mm^2 anterior hole (20A), and the control condition for the anterior holes (EO-A) according to each consonant sound (initial /t/, final /t/, initial /k/, and final /k/) are presented below. A summary of the reported results is shown in Appendix D.

TT Movement

Means, standard deviations, and TT movement for the consonants /t/ and /k/ in the initial and final position in the words "tap" and "pat" and for the consonant /k/ in the initial and final position in the words "cap" and "pack" are shown in Table 3-9 and 3-10, respectively. TT movement for all consonants is also illustrated graphically in Figure 3-19.

As shown in Figure 3-19, for the consonant /t/ in the initial and final position in the words “t̲ap” and “pat̲” an anterior TT movement was observed for the 20A-5 condition while a posterior TT movement was observed for the 20A and EO-A conditions. Paired t- tests indicated significant differences between the 20A-5 and 20A conditions for the consonant /t/ in both initial and final position (p = 0.0001). Analysis of variance likewise indicated significant differences between the 20A-5 and EO-A conditions for the consonant /t/ in both initial (p = 0.0001) and final position (p = 0.0001).

Table 3-9. Tongue Tip (TT) Movement Direction (MD), Means (M), and Standard Deviations (SD), in mm, for the Consonant /t/ in the Initial and Final Position for the 20A-5, 20A, and EO-A Conditions

	/tæp/			/pæt/		
	TT			TT		
	MD	M	SD	MD	M	SD
EO-A	P	2.01	1.05	P	1.14	0.60
20A	P	2.04	1.21	P	3.34	1.40
20A – 5	A	-1.25	1.33	A	-1.31	1.11

Table 3-10. Tongue Tip (TT) Movement Direction (MD), Means (M), and Standard Deviations (SD), in mm, for the Consonant /k/ in the Initial and Final Position for the 20A-5, 20A, and EO-A Conditions

	/kæp/			/pæk/		
	TT			TT		
	MD	M	SD	MD	M	SD
EO-A	A	-2.75	0.43	P	1.71	0.99
20A	A	-4.62	0.38	A	-2.03	1.00
20A – 5	P	0.52	1.03	P	4.16	0.63

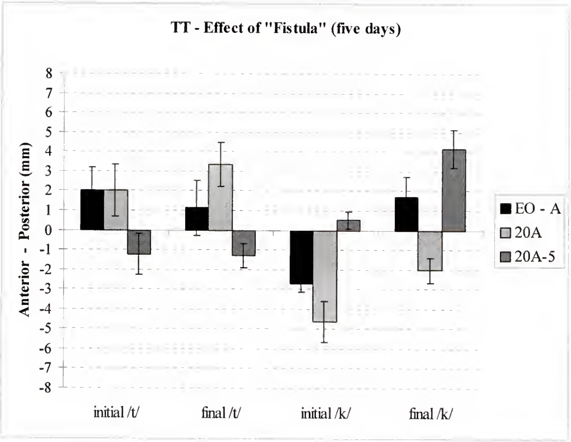


Figure 3.19. Means (mm) and Standard Deviations of Tongue Tip (TT) Movement (Anterior or Posterior) for the 20A-5, 20A, and EO-A Conditions

As shown in Figure 3-19, for the consonant /k/ in the initial and final position in the words "cap" and "pack" a posterior TT movement was observed for the 20A-5 condition. Additionally, for the consonant /k/ in the initial position in the word "cap", an anterior TT movement was observed for the 20A and the EO-A conditions. For the consonant /k/ in the final position in the word "pack", a posterior TT movement was observed for the EO-A conditions while an anterior TT movement was observed for the 20A conditions. Paired t- tests indicated significant differences between the 20A-5 and 20A conditions for the consonant /k/ in both initial and final position ($p = 0.0001$). Analysis of variance likewise indicated significant differences between the 20A-5 and EO-A conditions for the consonant /k/ in both initial ($p = 0.0001$) and final position ($p = 0.0001$).

Further review of the Figure 3-19 showed that, for the consonant /t/ in both initial and final position ("tap" and "pat"), an anterior TT movement was observed for the 20A-5 condition while a posterior TT movement was found for the 20A and EO-A conditions. In contrast, for the consonant /k/ in the initial position in the word "cap", a posterior TT movement was observed for the 20A-5 condition while an anterior TT movement was observed the 20A and EO-A conditions. Although for the consonant /k/ in the final position in the word "pack" the direction of TT movement was the same between the 20A-5 and EO-A conditions, greater amount of posterior TT movement was observed for the 20A-5 condition than was observed for the EO-A condition. Additionally, as seen in Figure 3-19 and Table 3-9 – 3-10, while the greatest posterior TT movement occurred for the 20A-5 condition for the consonant /k/ in the final position in the word "pack", the greatest anterior TT movement occurred for the 20A-5 conditions for the consonant /t/ in the initial and final position in the words "tap" and "pat".

TM Movement

Means, standard deviations, and TM movement for the consonant /t/ in the initial and final position in the words "tap" and "pat" and the consonant /k/ in the initial and final position in the words "cap" and "pack" are shown in Table 3-11 and 3-12, respectively. TM movement for all these consonants is also illustrated graphically in Figure 3-20.

As shown in Figure 3-20, for the consonant /t/ in both initial and final position a posterior TM movement was observed for the 20A-5, 20A, and EO-A conditions. Paired t-tests did not indicate significant difference between the 20A-5 and 20A conditions for the consonant /t/ in both initial ($p = 0.2977$) and final position ($p = 0.0606$). Analysis of variance did not indicate significant difference between the 20A-5 and EO-A TT conditions for the consonant /t/ in both initial ($p = 0.0572$) and final position ($p = 0.7768$).

As shown in Figure 3-20, for the consonant /k/ in the initial and final position an anterior TM movement was observed for the 20A-5 and EOA conditions. For the 20A condition, a trend for anterior TM movement was also observed for the consonant /k/ in the initial position while a posterior TM movement was observed for the consonant /k/ in the final position. Paired t- tests indicated significant differences between the 20A-5 and 20A conditions ($p = 0.0001$) for the consonant /k/ in both initial and final position. Analysis of variance did not indicate significant difference between the 20A-5 and EO-A TT means for the consonant /k/ in both initial ($p = 0.0140$) and final position ($p = 0.0997$).

Table 3-11. Tongue Medium (TM) Movement Direction (MD), Means (M), and Standard Deviations (SD), in mm, for the Consonant /t/ in the Initial and Final Position for the EO-A, 20A, and 20A-5 Conditions

	/tæp/			/pæt/		
	TM			TM		
	MD	M	SD	MD	M	SD
EO-A	N	-0.02	1.66	P	3.34	0.99
20A	P	0.89	0.60	P	2.45	0.65
20A – 5	P	1.28	1.16	P	3.23	0.84

Table 3-12. Tongue Medium (TM) Movement Direction (MD), Means (M), and Standard Deviations (SD), in mm, for the Consonant /k/ in the Initial and Final Position for the EO-A, 20A, and 20A-5 Conditions

	/kæp/			/pæk/		
	TM			TM		
	MD	M	SD	MD	M	SD
EO-A	A	-3.67	1.58	A	-2.20	1.27
20A	N	-0.42	0.94	P	1.40	0.86
20A – 5	A	-5.18	0.75	A	-3.21	1.33

Further review of the Figure 3-20 showed that, for the consonant /t/ in both initial and final position, a posterior TM movement was observed for the 20A-5, 20A, and EO-A conditions while for the consonant /k/ in the initial position an anterior TM movement was observed for these three conditions. Although for the consonant /t/ in the final position an anterior TM movement was also observed for the 20A-5 and EO-A conditions, a posterior movement occurred for the 20A condition. Additionally, as seen in Figure 3-20 and Table 3-11 – 3-12, while the greatest anterior TM movement occurred

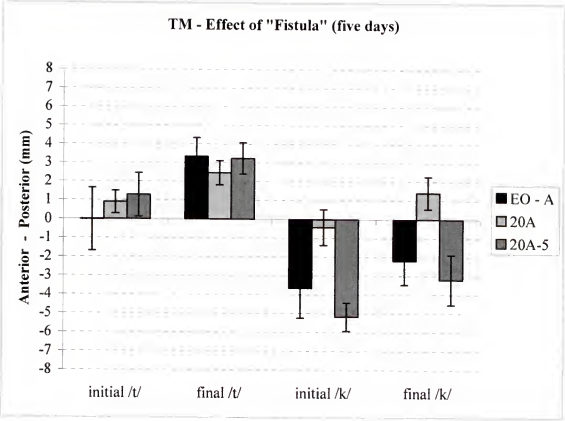


Figure 3.20. Means (mm) and Standard Deviations of Tongue Medium (TM) Movement (Anterior or Posterior) for the 20A-5, 20A, and EO-A Conditions

for the 20A-5 for the consonant /k/ in the initial position, the greatest posterior TM movement occurred for the 20A-5 and EO-A conditions for the consonant /t/ in the final position.

CHAPTER 4
DISCUSSION AND CONCLUSION

The primary purpose of this study was to investigate changes in tongue articulatory performance during speech in the presence of artificially induced openings (two locations and three sizes) through a palatal obturator covering an unrepaired cleft of the hard and soft palate. The results of this study revealed that location and size of the experimental openings have an effect on tongue tip (TT) and tongue medium (TM) movement.

A secondary purpose of this study was to identify differences in tongue articulatory movement after the subject had worn the experimental obturator with the 20 mm^2 anterior opening for five days. The results revealed that tongue articulatory movement was significantly affected under this condition.

The findings of this study will be discussed in order of the experimental questions posed. First, are there differences in tongue movements immediately after experimental palatal "fistulas" of varied sizes and locations have been created? Secondly, are there differences in tongue movements after the subject had worn the experimental obturator with the 20 mm^2 anterior "fistula" for five days? Answers to each of these questions will be discussed based on the results of the statistical analysis, then related to the findings from previous studies and finally interpreted based on the observed tongue movements.

Immediate Effects of Palatal "Fistula" Location on Tongue Movement

Anterior Openings

/t/ in the initial and final position

For the consonant /t/ in the initial position in the word "tap" posterior TT and TM movement was found to occur for the anterior holes. However, when tongue movement data for anterior openings (10A, 20A, and 30A) was compared to tongue movement data for control condition (EO-A), no statistically significant difference was found to occur for either TT or TM movement for this target sound. These findings do not support Cosman & Falk's (1980) findings that an anteriorly located oronasal fistula affects the production of pressure consonants that are produced anteriorly to, or at the locus of the opening. The authors commented that in an effort to compensate for the palatal opening, the place of articulation is sacrificed while the manner of articulation is preserved. As a result, the speaker articulates anterior sounds more posteriorly. Shelton & Blank (1984) also found a posterior place of articulation in the speech produced by one patient who had open palatal fistula located at the hard palate. More recently, Trost-Cardamone (1990) stated that palatal fistulas located at the foramen incisive typically influence pressure consonants produced with linguo-alveolar constrictions (/t/, /d/, /s/, z/) that are anterior to the openings. Additionally, several others authors (Hoch et al., 1986; Golding-Kushner, 1995; Karling, Larson, & Henningsson, 1993; Witzel, 1995) have reported linguo-palatal constrictions for lingual-alveolar consonants in the presence of anterior palatal fistulas.

The observed lack of significance in TT and TM movement for the consonant /t/ in the initial position in the word "tap" is likely related to laryngeal and respiratory adjustments that may have occurred for this subject in response to a perturbation in his speech system. Such physiologic adjustments were reported for this particular subject in previous research (Sapienza et al., 1996). That is, an increase in fundamental frequency as the size of opening increased was found to occur for this subject in the study conducted by Sapienza et al. (1986). This laryngeal adjustment was though to occur to assist the subject in generating the vocal intensity required for the loud speech task. An increase in nasal airflow with a concomitant decrease in intraoral pressure as the degree of oronasal coupling increased was also observed. A respiratory adjustment, which involved the expenditure of more lung volume as nasal airflow leakage increased, was also noted in this study. This respiratory adjustment was thought to occur as an active response necessary for achieving and maintaining the aerodynamic regulation of airflow for the loud speech task. The laryngeal and respiratory adjustments, therefore, might have minimized or even prevented further tongue articulatory movement during the subject's speech production. Additionally, the ability of the subject to control his articulators to produce a "clear" consonant stop even after a perturbation (experimental opening) is created to his speech system may have contribute to the observed findings. It should be emphasized that the subject in this study although not informed as to the purpose of this study, is an adult with training in speech-language-pathology. In other words, the subject's years of experience with adequate speech production in combination with his knowledge of how the speech is produced may have contributed to the observed findings.

Based on the literature (Witzel 1995; Golding-Kushner, 1995; 2001) it was expected that an anterior opening would affect lingual movement such that the TM position would raise and move posteriorly while the TT would lower and retract, resulting in a sound production perceived as a mid-dorsum palatal stop. That is, a "mid-palatal lingual contact with the tongue tip down" (Trost, 1981, page 196) would be expected to occur after perturbing the subject's speech system. It was also thought that more changes in TM would likely occur for an opening as large as 30 mm^2. It can be speculated, however, that the subject's physiological adjustments, articulatory skills and his knowledge of speech production resulted in no significant changes in place of articulation for the consonant /t/ in the initial position in the word "tap" for any of the anterior "fistulas". In addition, it should be noted that the investigator did not perceive changes in place of articulation for the consonant /t/ in the initial position in the word "tap" while recording tongue movement data.

For the consonant /t/ in the final position in the word "pat" posterior TT movement was observed to occur for all anterior openings. However, only the 20 mm^2 anterior "fistula" differed significantly from EO-A by moving 2.20 mm more posteriorly. There are three possible explanations for the observed TT retraction in association with the 20mm^2 anterior "fistula". First, lack of release of the consonant /t/ during the production of the word "pat" with an additional production of a flap for the target sound may have occurred. Second, co-articulation of the consonant /t/ in the word "pat" with the consonant /g/ in the word that follows ("again") may have occurred. That is, while producing the carrier phrase "Say pat again" a temporal overlap of articulatory movements for the consonant /t/ in the final position in the word "pat" and /g/ in the word "again" might have occurred. Third, the TM movement that occurred while producing the consonant /t/ in the final position could justify the observed retraction in TT. That is, when compared to EO-A, a more anterior TM movement was observed for the consonant /t /in the final position in the word "pat" for all anterior openings. Although only the 30

mm^2 anterior "fistula" differed significantly from EO-A by TT moving 2.87 mm more anteriorly, a general trend for more anterior TM movement was observed for all anterior openings. Findings observed for the consonant /t/ in the final position in the word "pat̲", therefore, suggest an attempt by the subject to move his tongue toward the anterior "fistula" by bunching the medium portion of the tongue and retracting the TT. The TT and TM movement changes observed for the consonant /t/ in the final position in the word "pat̲" could be viewed as the subject's attempt to avoid the undesirable speech effects resulting from a coupling between oral and nasal cavities. That is, the subject might have tried to avoid nasal air emission during the production of the lingual-alveolar sound (consonant /t/ in the final position) by using compensatory tongue strategies. As described by Kummer (2000), "…there may be nasal air emission during the production of lingual-alveolar sounds due to the fact that the tongue pushes air into the opening as it elevates for production" (page 283). Changes in TT and TM, therefore, would be necessary to avoid the undesirable speech effects while producing the consonant /t/ in the final position in the word "pat̲". These findings also support Witzel's (1995) statement that articulatory compensations (involving changes in place of articulation) might indicate an attempt by the speaker to occlude the fistula and consequently create pressure buildup while articulating lingual alveolar sounds. Warren (1986) explains these changes in articulatory placement as strategies developed by the speaker for satisfying the requirements of a pressure regulating system. Witzel (1995) notes have summarized Warren's regulating system,

> "[Warren's] theory of regulation control is based on the premise that normal speech results from the airflow and pressure of air, which are directed and controlled by the valves of the vocal tract. The flow and pressure of air through the oral cavity are reduced when the VP valve is inadequate or there is a fistula,

> causing problems with the formation of oral pressure sounds. In response to this inability to create sufficient airflow and pressure through the mouth or vocal tract, the individual may attempt to produce oral speech sounds by shaping the airflow in the lower vocal tract [in a more pressure effective place], where sufficient airflow and pressure can be generated" (page 140).

It should be noted, however, that the observed changes in TT and TM movement while producing the consonant /t/ in the final position in the word "pa_t_" did not seem to compromise the subject's speech. That is, the investigator did not perceive changes in place of articulation for the consonant /t/ in the final position while recording tongue movement data.

/k/ in the initial and final position

For the consonant /k/ in the initial and final position in the words "_c_ap" and "pa_ck_" anterior TT movement was found to occur for all anterior openings. However, for the consonant /k/ in the initial position in the word "_c_ap" only the two largest openings differed significantly from EO-A. That is, relative to the control condition, TT for the 20 and 30 mm^2 anterior "fistulas" moved 1.87 and 2.52 mm more anteriorly, respectively. For the consonant /k/ in the final position in the word "pa_ck_" all three anterior openings differed significantly from EO-A. That is, relative to the control condition, TT for the 10, 20 and 30 mm^2 anterior "fistulas" moved 1.99, 3.74 and 4.59 mm more anteriorly, respectively. Presence of the anterior "fistulas", therefore, affected the subject's production of the consonant /k/ (initial and final position) such that he moved his TT anteriorly.

For the consonant /k/ in the initial position in the word "_c_ap" an anterior TM movement was found to occur for all anterior openings. However, only the two largest openings differed significantly from EO-A. That is, relative to the control condition, TM for the 20 and 30 mm^2 anterior “fistulas” moved 3.25 and 3.46 mm more posteriorly, respectively. For the consonant /k/ in the final position in the word “pack” the two largest openings also differed significantly from EO-A. That is, relative to the control condition, TM for the 20 and 30 mm^2 anterior “fistulas” moved 3.60 and 4.68 mm more posteriorly, respectively. Presence of the two largest anterior “fistulas”, therefore, affected the subject’s production of the consonant /k/ (initial and final position) such that he moved his TM posteriorly in relation to the control condition.

Results from this study revealed that the two largest anterior “fistulas” always affected the subject’s production of the consonant /k/ (initial and final position) such that he moved his TT anteriorly and his TM posteriorly in relation to the control condition. These changes in TT and TM movement for the consonant /k/ in the initial and final position in the words “cap” and “pack” can likely be the result of the subject’s attempts to compensate for the negative effects (increased nasal air emission and decreased intraoral pressure) associated with coupling between oral and nasal cavities. That is, while producing the consonant /k/, the subject may have avoided the undesirable speech effects resulting from a “fistula” as large as 20 mm^2 by raising and pulling the dorsum of his tongue, retracting slightly his TM and moving slightly more anteriorly his TT (thrust). Taken together, the subject’s tongue would have a configuration of a trough. Although no information relative to the dorsum of the tongue was obtained in this study, the observed TT and TM tongue movements associated with consonant /k/ suggested the subject’s attempts to either occlude the “fistula” or increase intraoral space to consequently create pressure buildup while articulating the velar sound. As pointed out by Witzel (1995) changes in lingual articulatory placement are believed to occur in the presence of palatal fistulas as the speaker attempts to occlude the fistula while producing high-pressure consonants. Results obtained in this study further corroborate to Warren's theory that postulates that changes in articulatory placement may result from strategies developed by the speaker for satisfying the requirements of a pressure regulating system.

Posterior Openings

/t/ in the initial and final position

When tongue movement data for posterior openings (10P, 20P, and 30P) was compared to tongue movement data for control condition (EO-P), a statistically significant difference was found to occur for TT and TM movement for the largest opening for the consonant /t/ in the initial position in the word "tap". That is, relative to the control condition, TT and TM moved 1.45 and 2.13 mm more anterior for the largest "fistula", respectively. A possible explanation for this finding relies on the subject's attempt to produce a clear /t/ even when a posterior "fistula" as large as 30 mm^2 was created to his speech system. That is, the subject may have attempted to decrease the speech effects created by the largest posterior "fistula" by "enlarging" his oral cavity. That is, moving the entire tongue more anteriorly would increase the intraoral space created in front of the posterior opening and, consequently, reduce (even though not eliminating) the amount or air/sound escaping through the posterior opening decreasing, therefore, the effect of excessive nasal resonance.

One might consider that the occlusion of a "fistula" at the speech bulb would probably result in pulling the entire tongue posteriorly. This compensatory strategy would lead to a substitution of the place of articulation for the target consonant. It can be speculated, therefore, that the subject's physiological adjustments (Sapienza et al., 1996), articulatory skills and his knowledge of speech production may have resulted in changes for TT and TM movement, avoiding, however, a substitution of the place of articulation for the consonant /t/ in the initial position in the word "tap". It should be mentioned that the investigator did not perceive changes in place of articulation for the consonant /t/ in the initial position in the word "tap" while recording tongue movement data.

For the consonant /t/ in the final position in the word "pat" no statistically significant differences were found to occur for posterior openings for either TT or TM movement. One possibly explanation for this may be the lack of release for the /t/ in the final position. That is, with no release of the consonant /t/ in the final position, lingual compensatory strategies would not occur even for a "fistula" as large as 30 mm^2.

/k/ in the initial and final position

When tongue movement data for posterior openings (10P, 20P, and 30P) was compared to tongue movement data for control condition (EO-P), no statistically significant differences were found to occur for TT for the consonant /k/ in the initial position in the word "cap". This lack of significance may be likely related to laryngeal and respiratory adjustments that may have occurred for this subject in response to a perturbation on his speech system (Sapienza et al., 1996). That is, an increase in fundamental frequency as the size of opening increased was found to occur for this subject in the study conducted by Sapienza et al. (1986). This laryngeal adjustment was though to occur to assist the subject in generating the vocal intensity required for the loud speech task. An increase in nasal airflow with a concomitant decrease in intraoral pressure as the degree of oronasal coupling increased was also observed. A respiratory adjustment, which involved the expenditure of more lung volume as nasal airflow leakage increased, was also noted in this study. This respiratory adjustment was thought to occur as an active response necessary for achieving and maintaining the aerodynamic regulation of airflow for the loud speech task. The laryngeal and respiratory adjustments, therefore, might have minimized or even prevented further tongue articulatory movement during the subject's speech production. It also may be related to the ability of the subject to control his articulators to produce a "clear" consonant stop even after a perturbation (experimental opening) is created in his speech system. As mentioned earlier, the subject in this study is an adult with training in speech-language-pathology. Therefore, the subject's physiological adjustments in combination with years of experience with adequate speech production and his knowledge of how speech is produced may have contributed to the observed findings.

A statistically significant difference, however, was found to occur for TT for the consonant /k/ in the final position in the word "pack". That is, relative to the control condition, TT moved 1.95 and 6.60 mm more anterior for the two largest "fistulas", respectively. This finding suggested that the subject might have attempted to decrease the speech effects created by the two largest posterior "fistulas" by "enlarging" his oral cavity. Again, moving the entire tongue more anteriorly would increase the intraoral space created between the tongue and the posterior opening and, consequently, reduce (even though not eliminating) the amount or air/sound escaping through the posterior opening decreasing, therefore, the effect of excessive nasal resonance. Results obtained in this study again corroborate Warren's theory that postulates that changes in articulatory placement may result from strategies developed by the speaker for satisfying the requirements of a pressure regulating system.

Although changes in TM movement were expected to occur, no statistically significant difference was found for TM movement for the consonant /k/ either in the initial or in the final position in the words "c̲ap" and "pac̲k̲". Again, the subject's physiological adjustments and ability to control his articulators to produce a "clear" consonant stop even after a perturbation (experimental opening) is created in his speech system may have resulted in no changes in TM movement during production of the consonant /k/.

The influence of posterior fistula(s) on place of articulation is not well documented in the literature. Trost-Cardamone (1990) has reported the effects of posterior fistula(s) on place of articulation for /k/ and /g/ sounds. The few others studies that have addressed the affects of posterior palatal fistulas on speech have referred only to the presence of hypernasality, excessive nasal air emission and weak pressure consonants (Hennigsson & Isberg, 1990; Ross & Johnston, 1972). That is, no data regarding specific changes in tongue articulation have been presented relative to posterior fistula(s). With fistulas occurring less often at the soft palate (Lindsay, 1971; McWilliams, Morris, & Shelton, 1990; Palmer et al., 1969; Peer et al, 1954) it is not surprising that data on the effects of posteriorly located fistulas on speech are not available. This study showed that compensatory strategies during production of the consonant /t/ and /k/ occurred as result of posterior "fistulas". More information on tongue movements associated with posterior openings, however, is still necessary. Studies investigating the effects of controlled openings in individuals that have received training for speech production would help for the understanding of the impact of posterior openings on tongue movement.

Anterior vs. Posterior Openings

Statistical analysis revealed that location was a significant factor for both TT and TM movement for the two consonants in both positions (/t/ and /k/ in the initial and final position in the words "tap", "pat", "cap" and "pack" respectively). However, TT and TM movement changes between anterior and posterior location was also dependent on the size of the "fistula". That is, the greatest number of significantly different amounts of tongue movement between anterior and posterior "fistulas" occurred for 20 and 30 mm^2 openings. The only lingual site and consonant type that did not show a significant location difference was TT for the consonant /t/ in the final position. All other target consonants (/t/ in the initial position and /k/ in the initial and final position) showed significant differences in the amount of tongue movement between anterior and posterior "fistulas".

Information derived from this study, therefore, revealed that the subject may possibly have used different articulatory strategies to overcome the undesirable effects created by either an anterior or a posterior coupling of the oral and nasal cavities. These articulatory changes, however, were most pronounced for the two largest holes (20 and 30 mm^2).

Some unexplained results occurred in this study. That is, statistically significant differences in tongue movements were found between the anterior and posterior control conditions (EO-A vs EO-P) for TT for the consonant /t/ in the initial position and TM for the consonant /k/ in the final position. Differences in TT and TM movement between these two control conditions were not expected to occur in any instance.

Clinical implications of location of the fistula on tongue movement

The clinical implication of these findings is that a subject with palatal fistula might use articulatory strategies such as those found in this single-subject study to overcome the undesirable effects created by anterior and posterior coupling of the oral and nasal cavities.

As suggested in this single-subject study, the articulatory strategies associated with anterior and posterior "fistulas" were most pronounced for the two largest "fistulas". Special attention, therefore, should be taken when evaluating the lingual articulatory performance of a patient who has palatal fistula as large as 20 mm^2.

In this study, the effect of an anterior or posterior "fistula" on tongue movement was influenced by the speech sample. By examining the significant results of palatal fistula location for TT it appeared that location influenced TT movement for /t/ more than for /k/. That is, for TT, the greatest number of significant differences between anterior and posterior "fistulas" was found for the consonant /t/ in the initial position. These findings could be explained by considering the tongue region involved in producing linguo-alveolar consonants. That is, TT might be expected to be more involved during production of linguo-alveolar consonants than during production of velar consonants. Additionally, significant results of palatal fistula location for TM indicated that location appeared to influence TM movements for /k/ more than for /t/. That is, for TM, the greatest number of significant differences between anterior and posterior "fistulas" was found for the consonant /k/ in the initial and final position. These findings could be explained by considering the tongue region that is involved for producing back consonants. That is, TM might be expected to be more involved during production of velar consonants than during production of linguo-alveolar consonants.

As shown in this study, speech samples that include words starting with /t/ might be helpful while investigating TT movements related to anterior and posterior palatal fistulas. Speech samples that include words starting and ending with /k/ might be helpful while investigating TM movements related to palatal fistulas.

Immediate Effect of Palatal "Fistula(s)" Size on Tongue Movement

Size and Anterior Openings

Statistical analysis revealed that size of the anterior "fistula" was a significant factor for both TT and TM movements for the consonant /t/ in the final position in the word "pat" and the consonant /k/ in the initial and final position in the words "cap" and "pack". That is, for these target consonants, the greatest number of significantly different amounts of TT and TM movement occurred between the control condition (experimental obturator completely occluded) and the two largest anterior openings (20 and 30 mm^2).

Clinical studies investigating the relationship between size of fistula and speech outcome have suggested that while small fistulas (not defined as to mm^2) may be nonsymptomatic for speech (Krause, Tharp, and Morris, 1976; Oneal, 1971; Randall, 1986), moderate and large fistulas (not defined as to mm^2) often result in speech problems (Shelton & Blank, 1984). Findings from the present study objectively support the reported literature that the greater the size of the opening, the greater the amount of TT and TM movement observed for the consonant /t/ in the final position in the word "pat" and the consonant /k/ in the initial and final position in the words "cap" and "pack". That is, more changes in TT and TM movement occurred for these target consonants when openings of larger sizes were present at the anterior palate. A possible explanation for this finding could be that the subject attempted to compensate for larger openings by changing slightly tongue placement while producing the target consonants in order to achieve the pressure requirements for production of high-pressure consonants.

Results from this study are also in agreement with the findings of experimental studies that have attempted to investigate the relationship between the degree of the speech impairment and the size of the anterior holes (Richtner, 1986; Sapienza et al., 1996). These studies have demonstrated a trend for more speech problems as the size of the anterior opening increases. While examining the effects of location and size of controlled openings ("fistulas") through the hard and soft palates on speech articulation and resonance Richtner (1986) found mild distortions associated with small fistulas (5 mm^2) with greater distortions occurring with increased openings (20 and 30 mm^2). Another study focusing on the investigation of respiratory, laryngeal, and supralaryngeal function associated with experimental couplings of the oral and nasal cavities also indicated a consistent increase of nasal airflow with a concomitant decrease in intraoral pressure as the size of the anterior experimental holes increased (Sapienza et al., 1996).

Even though in this study significant differences in the amount of TT and TM movement did not occur for the smallest hole size (10 mm^2) other studies have demonstrated that a fistula as small as 4.5 mm^2 can have an impact on speech (Henningsson and Isberg, 1987; Karling, Larson, and Henningsson, 1993). Such studies, however, were investigating the effects of hole sizes on nasal resonance and nasal flow and oral pressure and did not measure articulatory displacement. While a small hole might directly affect airflow and air pressure, it is conceivable that a change in tongue movement would likely occur when opening size increases. That is, as suggested by Hennigsson and her colleagues' presence of a small coupling between nasal and oral cavities would be enough to result in an immediate loss of airflow and decrease in intra-oral pressure during speech production. Small openings, however, might not be enough to result in immediate tactile and kinesthetic feedback differences that could affect place of articulation. Additionally, the subject in this study has training in speech-language-pathology and this training might have affected production such as to prevent changes in tongue movements that could be expected with "fistulas". Perhaps such changes could have been found for a lesser skilled speaker even for smaller openings.

In summary, this study has demonstrated that an anterior "fistula" of at least 20 mm^2 was required to cause significant changes in TT and TM movement. However, when listening to the subject's speech during the experimental conditions, it was noted that accurate target sounds were preserved even for the two largest anterior fistulas". This finding suggested that even though the /t/ and /k/ sounds were produced either more anteriorly or more posteriorly as identified by articulatory measurements, loss of the perceived phoneme characteristics did not occur.

Size and Posterior Openings

Statistical analysis revealed that size of the opening was an important factor for posterior holes for both TT and TM movements for the consonant /t/ in the initial position in the word "tap" as well as TT movement for the consonant /k/ in the final position in the word "pack". That is, for these target consonants significantly different amounts of tongue movement occurred between the control condition (EO-P) and the largest opening (30 mm^2 holes) as well as between the smallest hole (10 mm^2) and the largest opening (30 mm^2). As for anterior "fistula", findings from posterior "fistulas" also suggested that the subject attempted to compensate for larger openings by slightly changing tongue placement while producing accurate target consonants in order to achieve the pressure requirements for production of high-pressure consonants.

Clinical implications of size of the fistula on tongue movements

The clinical implication of these findings is that a subject with palatal fistula might possibly use articulatory strategies such as those found in this single-subject study to overcome the undesirable effects created by anterior and posterior coupling of the oral and nasal cavities of 20 and 30 mm^2. That is, clinically, differences in TT and TM movement could be expected to occur for a palatal fistula as large as 20 mm^2. It is unknown whether fistulas ranging between 10 and 20 mm^2 would also result in significant differences in TT and TM movements. This study only investigated holes sizes 10 mm^2 decrements apart (10, 20 and 30 mm^2). Additionally, one could speculate that a subject who has less or no training in speech production might use more extreme articulatory strategies associated with palatal fistulas for an opening smaller than 20 mm^2. That is, a lesser skilled speaker with a fistula could show TT and TM movement that differ from those obtained in this case study. For example, a non-trained speaker might show a greater amount of TT and TM movement as he/she attempts to either occlude the anterior fistula or make constrictions behind the anterior fistula in order to create enough pressure while articulating high-pressure consonants (Warren, et al., 1986). Larger amount of TT and TM movement could result in perceived changes of place of articulation. However, the speaker skilled in speech-language-pathology would likely be more careful and attentive to any change that could result in distortions of place of articulation and therefore not choose a strategy that would result in such a change of articulation.

Results from this study also indicated the importance of the selection of speech sample that facilitates the interpretation of the tongue movement as a result of a palatal fistula. That is, as shown in this study, a word starting and ending in /t/ as well as a starting and ending in /k/ revealed differences in TT and TM movements with the larger anterior openings. These words, therefore, could be selected in order to identify possible effects of larger anterior and posterior palatal fistulas on tongue movements.

Effects of Experiencing an Experimental Palatal "Fistula" for Five Days

The primary goal of this study was to investigate the immediate effects of experimentally induced palatal "fistulas" of varied location and size on tongue movement. In addition, the present study perturbed the oral system by experimentally coupling the oral and nasal cavities for a period of five days to determine the impact this coupling would have on tongue movement. Interpretation of the results found in this study is reported below. For means of comparison the findings for immediate changes in tongue movement for the 20 mm^2 opening already reported in the previous session will be repeated followed by the findings observed for the 20 mm^2 opening after five days.

/t/ in the initial and final position

For the consonant /t/ in the initial position in the word "tap" no significant differences were found for TT movement immediately after creating the "fistula" (condition 20A) compared to the control condition (EO-A). That is, a perturbation of the system (i.e. anterior "fistula of 20 mm^2) did not result in an immediate TT compensatory strategy when compared to the control condition while the subject produced the consonant /t/ in the initial position in the word "tap". However, after five days in which the subject experienced the 20 mm^2 anterior opening (condition 20A-5), there was a change in TT movement direction (from posterior to anterior movement). This change in TT movement for the 20A-5 condition was statistically significantly different from both the 20A and the EO-A conditions.

For the consonant /t/ in the final position in the word "pat" posterior TT movement occurred immediately after creating the "fistula" (condition 20A) and this posterior TT movement differed significantly in magnitude from the movement observed for the control condition (EO-A). That is, findings obtained in this study suggested that a perturbation of the system (i.e. anterior "fistula" of 20 mm^2) resulted in an immediate TT compensatory strategy (i.e. TT more retracted) for this target sound. After five days in which the subject experienced the 20 mm^2 anterior opening (condition 20A-5) there was a change in TT movement direction (from posterior to anterior movement). This change in TT movement for the 20A-5 condition was statistically significantly different from both the 20A and the EO-A conditions. The longer time for the subject to experience the 20 mm^2 opening resulted, therefore, in a change in direction of TT (from posterior to anterior) movement for both target sounds (/t/ in the initial and final position).

A change in tongue movement over time, however, was not observed when TM movement was investigated. That is, for the consonant /t/ in the initial and final position in the words "tap" and "pat" posterior TM movement occurred immediately after creating the 20 mm^2 anterior "fistula" (20A) and also after the subject had worn the experimental obturator with the 20 mm^2 opening (condition 20A-5) for five days. Additionally, no statistical differences were found between the 20A-5 and the 20A conditions as well as between the 20A-5 and the EO-A conditions. Immediate and sustained perturbation (i.e. an anterior opening of 20 mm^2), therefore, did not influence TM movements for the consonant /t/ in the initial and final position.

It is not clear why a change in direction of TT occurred over time for the production of the consonant /t/ in both initial and final position in the words "tap" and "pat". Information regarding superior and inferior tongue movement during production of these two target sounds would likely add to the understanding of the observed change in TT direction for the sustained opening. That is, one could speculate that TM raising would occur during the production of the consonant /t/ in the initial and final position as a result of the subject's attempts to occlude the anterior "fistula". This TM raising would lead the tongue to make other articulatory adjustments (i.e. TT moving more anteriorly) to allow the subject to still produce a clear /t/. Superior and inferior measurements, therefore, would be helpful to clarify findings obtained in this study.

/k/ in the initial and final position

For the consonant /k/ in the initial and final position in the words "cap" and "pack" anterior TT movement occurred immediately after creating the "fistula" (condition 20A) and this anterior TT movement differed significantly from the control condition (EO-A) for both target sounds. Findings obtained in this study, therefore, suggested that a perturbation of the system (i.e. anterior "fistula" of 20 mm^2) resulted in an immediate TT compensatory strategy (i.e. TT thrust) while the subject produced the consonant /k/ in both initial and final position in the words "cap" and "pack". However, after five days in which the subject experienced the 20mm^2 anterior opening (condition 20A-5) a more posterior TT movement was observed for the consonant /k/ in the initial and final position in the words "cap" and "pack". This TT movement for 20A-5 differed significantly from both the 20A and the EO-A conditions. TT findings for the consonant /k/ in the initial and final position in the words "cap" and "pack" suggested that a perturbation of the system (i.e. anterior “fistula” of 20 mm^2) resulted in immediate TT compensatory strategies (i.e. TT thrust) that even if effective immediately (in helping to maintain place of production or helping to avoid distortions, for example) may not be necessarily efficient over time. That is, given a longer time with the perturbation (i.e. five days with the anterior “fistula” of 20 mm^2) the subject might have begun to habituate to such perturbation in his speech system becoming, therefore, less conscious of his speech while producing the target sounds. As a result, TT movement over time would be similar to that observed for the control condition.

TM findings obtained in this study revealed that a more posterior TM movement occurred immediately after creating the “fistula” (condition 20A) for the consonant /k/ in both initial and final position in the words “cap” and “pack”. This TM movement differed significantly from the control condition (EO-A) for both target sounds. Findings obtained in this study, therefore, suggested that a perturbation of the system (i.e. anterior “fistula” of 20 mm^2) resulted in an immediate TM compensatory strategy (i.e. TM slightly retracted) while the subject produced the consonant /k/ in both initial and final position in the words “cap” and “pack”. After five days in which the subject experienced the 20 mm^2 anterior opening (condition 20A-5) a more anterior TM movement was observed for 20A-5. This TM movement for 20A-5 was significantly different from 20A but did not differ from the control condition EO-A. TM findings found for the consonant /k/ in the initial and final position in the words “cap” and “pack” suggested, therefore, that a perturbation of the system (i.e. anterior “fistula” of 20 mm^2) resulted in immediate TM compensatory strategies (i.e. slightly retraction) that even if effective immediately (in helping to maintain place of production or helping to avoid distortions, for example) may not be necessarily efficient over time. Given a longer time with the “anterior fistula” the subject might have begun to habituate with such perturbation in his speech system becoming, therefore, less conscious of his speech while producing these two target sounds. As a result, TM movement over time would be similar to that observed for the control condition.

Findings for the consonant /k/ in the initial and final position in this study revealed, therefore, a similar trend for both TT and TM in which sustained perturbation resulted in tongue movement that was similar to that observed for the control condition.

Clinical implications of experiencing an experimental palatal "fistula" for five days

In summary, experiencing a 20 mm^2 experimental palatal "fistula" for five days had a significant effect on TT and TM for the consonants /t/ and /k/ in the initial and final position when these tongue movements were compared to those observed immediately after creating the 20 mm^2 experimental palatal "fistula". Tongue movement after five days was not different than tongue movement observed during the control condition, indicating that the subject may have "normalized" his articulatory production to that previously observed with the control condition.

Results from this study, therefore, supported previous findings reported by Pinborough-Zimmerman et al. (1997) in which sustained fistula obturation (i.e. fistula closure using an acrylic palatal obturator for four to seven weeks) affected significantly the speech outcome of 15 children with palatal fistula secondary to a repaired cleft palate. That is, Pinborough-Zimmerman and her colleagues found improvement in articulation and nasality scores for sustained postobturation condition (i.e. four to seven weeks after occluding the fistula with an acrylic palatal obturator) when compared to the preobturation and to the immediate postobturation conditions. However, the authors did not find significant differences in articulation and nasality scores between the preobturation and the immediate postobturation conditions. The only significant improvement between these two conditions (i.e. preobturation and immediate postobturation) occurred for nasal emission measures. As stated by Pinborough-Zimmerman and her colleagues, their findings were consistent with those reported by D' Antonio's et al. (1993) which showed more reduction in frequency of nasal air emission and perceived oral pressure than in hypernasality immediately after obturation of a fistula. Pinborough-Zimmerman and her colleagues further stated that their findings did not agree with those obtained by Henningsson and Isberg (1987) which showed immediate meaningful improvement in speech intelligibility and resonance after fistula obturation. Pinborough-Zimmerman and her colleagues emphasized in their study that improvement in articulation occurred only after sustained obturation of fistula. Therefore, the authors advocated long-term obturation of the fistula prior to the formulation of surgical and speech intervention plans associated with palatal fistulas.

Findings in the present study suggest the importance of obtaining long-term data while investigating the effects of a palatal opening on speech. That is, although in this study lingual compensatory strategies (i.e. posterior and anterior movement of the tongue) were identified immediately after perturbing the subject's speech system, these compensatory strategies may not have properly reflected properly how the subject's speech system responded for a perturbation over time (i.e. five days with the anterior "fistula").

Determining the effects of sustained palatal "fistulas", therefore, can add in the overall understanding of the speech motor function related to this particular palatal opening. This understanding will provide additional information that can help to achieve more reliable management decisions regarding speech therapy timing and also to select the most appropriate speech therapy approach for the correction of articulatory disorders related to palatal fistulas. That is, one could suggest, based on the findings in this study, that palatal obturation prior to speech therapy could benefit those individuals who exhibit articulatory error patterns associated with palatal fistula as long as the obturation was sustained. Immediate palatal obturation (i.e. obtained only during speech therapy or assessments), however, would not result in a pattern of articulation that would be efficient over time. While more data is still warranted to further substantiate these finings, care must be taken with the interpretation of findings after both immediate and sustained obturation of palatal fistulas.

Strengths and Limitations

Strengths

This study was primarily designed to investigate changes in tongue articulatory performance during speech in the presence of artificially induced openings (two locations and three sizes) through an experimental palatal obturator covering an unrepaired cleft of the hard and soft palate. More specifically, this study focused on anterior-posterior tongue movement changes as a function of palatal openings. It is a common occurrence for individuals with palatal fistulas to have changes in place of articulation in which the medium dorsum of the tongue contacts the palate during production of linguo-alveolar and velar consonants. This more posterior place of articulation is commonly described by those involved with the management of the speech of individuals with palatal fistulas. However, only few studies (Trost, 1981; Mitchi et al., 1986; Yamashita & Mitchi, 1991) have instrumentally described changes in tongue placement such as middorsum palatal stops. In addition, these studies only investigated middorsum palatal stops that are produced by individuals with repaired cleft palate with no reports associated with middorsum palatal stops as produced by individuals with palatal fistulas.

Other studies have examined the effect of experimental palatal fistulas of varied size and location on respiratory and laryngeal function (Sapienza et al., 1996) and on resonance, nasal airflow, and intraoral pressure pressure (Richtner, 1986) rather than the effect palatal fistulas with varied size and locations has on tongue movement. This study, therefore, set the preliminary step in determining articulatory performance by measuring, objectively, tongue movement changes in response to controlled openings. Findings of this study indicated that size and location of palatal openings had an effect on articulation. Findings from this study help to clarify some of the effects of abnormal tongue movements resulting from palatal “fistulas” by providing objective information of how openings of varied size and location may affect tongue movement.

Another goal of this study was to describe tongue articulatory movement after the subject had worn the experimental obturator with the 20 mm^2 anterior opening for five days. Findings obtained in this study revealed changes in lingual displacement in the presence of a sustained palatal opening that differed from those tongue movements observed immediately after creating the 20 mm^2 anterior “fistula”. Establishing preliminary data on short and long-term effects of controlled openings on tongue movement might help guide therapeutic intervention of persons with palatal openings. That is, findings in this study suggested that a more efficient pattern of articulation might result from sustained palatal obturation than from immediate palatal obturation.

Sustained obturation, therefore, would be considered prior to speech therapy as well as prior to assessment.

Limitations

The single-subject in the present study has been wearing a speech palatal obturator throughout his life to close his unrepaired cleft palate. Caution should be applied to the generalization of these findings to other subjects wearing a speech palatal obturator and/or presenting with palatal fistulas. That is, the fact that the "fistulas" were created after the subject had mastered speech production (not during the stages of speech acquisition) warrant the need for replication of this study with subjects with varied ages. Objective tongue movement data obtained for children who has developed palatal fistulas during the period of language acquisition might differ than those obtained in this study. In the former case, more tongue placement compromise would be identified by instrumental measurements.

The present findings have been obtained from a subject with extensive training in speech-language pathology as well as years of speech therapy during childhood. It is quite likely that familiarity with the technicalities of speech production may have influenced his articulatory performance. The subject in this study might be conscious and attentive to his speech and might be able to avoid compensations that would naturally occur for a speaker not so aware of the process of speech production and the effects of fistula on speech. Therefore, more consistent and severe compromise of articulation could be identified instrumentally for a naïve subject.

In this study, TT and TM movement was measured after gluing transducers on the tip and mid portion of the tongue. Although additional information would have been gained had the transducers been positioned at the posterior portion of the tongue (dorsum) this location was avoided in the present study to reduce the amount of discomfort of the subject while running the experiment, especially given the number of recording sessions. It is likely that measures obtained with a transducer placed on the dorsum of the tongue might have more accurately reflected the effects of posterior fistulas on tongue movements at least for the consonant /k/. As the dorsum of the tongue is directly involved with the production of velar consonants, information regarding movement of the dorsum of the tongue would definitely supplement the findings of this study. That is, placing a transducer on the dorsum of the tongue would better reflect whether the back of the subject's tongue moved towards the place in which posterior openings (speech bulb) were drilled through the subject's obturator.

The subject in this study was producing speech while wearing a series of five sensors glued to his articulators. While not invasive, the sensors are intrusive and variances in tongue placement while wearing the experimental obturator could occur due to tactile and kinesthetic feedback. To minimize this potential problem, an additional recording session was included in this study prior to starting data acquisition of interest, so the participant could become accustomed to the transducers before the recording of the data analyzed in this study.

Findings of this study are limited to measures of anterior-posterior tongue movement. Obtaining superior-inferior measures of tongue movement would likely add in the overall understanding of the effects of the controlled experimental palatal "fistulas" on tongue movement. That is, data about superior-inferior movement of the tongue would add important information regarding tongue displacement towards the openings, supplementing the finding regarding the anterior-posterior orientation of the tongue.

Additionally, findings of this study are limited to measures of anterior-posterior tongue movement during production of stop consonants. Information on tongue movement during production of fricatives would also contribute to the further understanding of the effects of palatal fistulas on speech. That is, because retraction of the tongue has been also reported in association with palatal fistulas during production of fricative sounds, it would be interesting to observe whether kinematic measures would also reflect changes in tongue movements associated with these consonants.

Aerodynamic measurements would also contribute in the overall understanding of the findings obtained in this study by revealing whether changes in the amount of airflow and air pressure that are expected to occur in the presence of palatal "fistulas" would be accompanied or not by changes in lingual articulatory movements. That is, one could suggest that tongue movement changes would occur to compensate for an increase in nasal airflow and a decrease in intraoral pressure that would result from palatal "fistulas". Based on the findings obtained in this study, these effects would be expected to become more prominent for openings greater than 20 mm^2. Additionally, aerodynamic measurements would further contribute to the understanding of the effects of immediate and sustained perturbation on speech.

The subject in this study was perceptually judged by the investigator to have mastered normal speech while wearing the experimental obturator before and after any hole was drilled. Although no standardized test was used to perceptually evaluate the effects of these experimental openings on tongue placement, the investigator did not perceive changes in place of articulation during data acquisition. Variations in tongue placement, however, were detected instrumentally. Standardized perceptual tests, therefore, should be used in the future to help establishing whether minor variations in tongue movements identified by instrumental tests can be identified perceptually.

Speech problems are not always present in individuals with palatal fistulas. Variations in speech behavior among individuals with abnormal oronasal coupling that occurs during the period of speech and language development may explain why speech problems are not always associated with palatal fistulas (Henningsson and Isberg, 1990). When present, however, a symptomatic fistula may cause deterioration in speech quality and intelligibility, and it can lead to significant communication impairment (Witt & D'Antonio, 1983). Caution should be applied to the generalization of findings from this study to other subjects presenting with palatal fistulas. That is, presence of a palatal fistula would not necessarily predict changes in lingual articulatory movement.

Further Research Questions

This study represents an initial attempt to quantify lingual articulatory movement associated with palatal fistulas while using EMA. Overall, the findings of this study revealed changes in lingual articulation. Although these changes were suggestive of compensations, the nature of these compensations was not always clear. Therefore, further investigations are warranted. Replication of this study in a larger population wearing an experimental obturator could provide additional evidence to support the data obtained in this study. Quantitative information of the effects of fistula shape on tongue movement would further contribute to the understanding of the effects of palatal fistulas on speech. That is, lingual articulatory compensations would be expected to vary among individuals with palatal fistulas of varied shape. These variations in lingual compensations would occur as a result of subject's attempts to achieve the desirable speech production. Here one must remember that not all individuals with palatal fistulas demonstrate speech problems. Shape of the fistula, therefore, might become an important variable predicting changes in lingual articulatory movement that might result from palatal fistulas.

It would be also interesting to determine the relationship between the quantitative measures of tongue movement and the perceptual outcomes of palatal fistula. Studies such as this could help to identify whether listeners can perceive slight changes in tongue movements that are identified instrumentally.

Obtaining superior-inferior measures of tongue movement would also likely add in the overall understanding of the effects of the controlled experimental palatal “fistulas” on tongue movement.

Summary and Conclusions

The effects of a palatal fistula(s) on speech are well recognized by professionals involved in the management of individuals with cleft palate. Little objective information, however, is reported in the literature on the effects of palatal fistula(s) on place of articulation.

The purpose of this single-subject study was to investigate speech articulatory performance following experimentally controlled openings through a palatal obturator worn by an adult male with an unrepaired cleft of his hard and soft palate. Tongue movement for the consonant /t/ and /k/ in the initial and final position was measured immediately after creating “fistulas” of three different sizes at two locations, one at a time, using Eletromagnetic Articulography (EMA). Tongue movement for these two consonants was also measured after five days in which the subject had worn the 20 mm2 anterior “fistula”.

The results of this study revealed that location and size of the experimental openings affected tongue tip (TT) and tongue medium (TM) movements. Anterior palatal “fistulas” affected both TT and TM movement when the subject produced the consonant /k/ in the initial and final position in the words “cap” and “pack and the consonant /t/ in the final position in the word “pat”. Changes in tongue movement in the presence of anterior “fistulas” occurred more often for the velar consonant /k/ than for the linguo-alveolar /t/. Posterior palatal “fistulas” affected both TT and TM when the consonant /t/ in the initial position in the word “tap” was produced. Posterior palatal “fistulas” also affected TT when the consonant /k/ in the final position in the word “pack” was produced. No change in TT and TM movement was found for the consonant /t/ in the final position in the word “pat” or in the consonant /k/ in the initial position in the word “cap”. Changes in tongue movement in the presence of posterior “fistulas”, therefore, occurred less often than in association with anterior “fistulas”. Additionally, significant changes in tongue movement occurred for the two largest anterior and posterior “fistulas” (20 and 30 mm^2).

Results of this study also revealed that tongue articulatory movements were significantly affected after the subject had worn the 20 mm^2 experimental palatal “fistula” for five days when these tongue movements were compared to those observed immediately after creating the 20 mm^2 experimental palatal “fistula”. Tongue movement after five days was not different than tongue movement observed during the condition in which the experimental obturator was completely occluded.

Findings of this study further corroborate the theory postulated by Warren (1986) who suggests that changes in articulatory placement may result from strategies developed by the speaker for satisfying the requirements of a pressure regulating system. Findings from this study also suggest that the lack of changes in articulatory placement may result from physiological adjustments that may have occurred during the speaker's production. The overall findings of this study therefore support the existence of interrelationships among all systems (respiratory, laryngeal and articulatory) involved in speech production. That is, in an attempt to maintain appropriate levels of intraoral air pressure during speech, compensations to overcome the effects of a perturbation on the subject's speech system could have occurred in any or all of systems. While articulatory compensations have been identified in this study for some of the conditions, lack of these same compensations might have been overshadowed by adjustments from the other laryngeal and respiratory systems.

The clinical implication of these findings is that a subject with palatal fistula might use articulatory strategies such as those found in this single-subject study to overcome the undesirable effects created by anterior and posterior coupling of the oral and nasal cavities of 20 and 30 mm^2. Findings in the present study also suggest the importance of obtaining long-term data while investigating the effects of a palatal opening on speech.

APPENDIX A
CONDITIONS

Condition 1: experimental obturator with no holes drilled through it (baseline for anterior holes)

Condition 2: experimental obturator with 10 mm^2 hole (anterior location)

Condition 3: experimental obturator with 20 mm^2 hole (anterior location)

Condition 4: experimental obturator with 30 mm^2 hole (anterior location)

Condition 5: experimental obturator with no holes drilled through it (baseline for posterior holes)

Condition 6: experimental obturator with 10 mm^2 hole (posterior location)

Condition 7: experimental obturator with 20 mm^2 hole (posterior location)

Condition 8: experimental obturator with 30 mm^2 hole (posterior location)

Condition 9: experimental obturator with 20 mm^2 hole but five days after the subject wearing the experimental obturator with a 20 mm^2 hole

APPENDIX B
RELIABILITY OF TONGUE MOVEMENT MEASUREMENTS

	TT (%)	TM (%)
tap	99	99
pa**t**	98	90
cap	97	85
pa**ck**	85	82
Total	99	99

APPENDIX C

SUMMARY OF RESULTS: TONGUE TIP (TT) AND TONGUE MEDIUM (TM) MOVEMENT FOR EXPERIMENTAL CONDITIONS

	TT	
	INITIAL POSITION /tæp/	FINAL POSITION /pæt/
/t/	Posterior movement for Anterior holes Anterior movement for Posterior holes Statistically Significant Differences: A) Location: EO-A vs EO-P 10A vs 20P 20A vs 20P 30A vs 30P B) Size: EO-P vs 30P (30P more anterior than EO-P)	Posterior movement for Anterior holes Posterior movement for Posterior holes Statistically Significant Differences: A) Location: anterior conditions did not differ from posterior conditions B) Size: EO-A vs 20A (20A more posterior than EO-A)
	/kæp/	/pæk/
/k/	Anterior movement for Anterior holes Anterior movement for Posterior holes Statistically Significant Differences: A) Location: 20A vs 20P B) Size: EO-A vs 20A EO-A vs 30A 10A vs 30A (20A and 30A more anterior than EO-A) (10A more anterior than 30A)	Anterior movement for Anterior holes Anterior movement for Posterior holes Statistically Significant Differences: A) Location: 20A vs 20P B) Size: EO-A vs 10A EO-A vs 20A EO-A vs 30A 10A vs 30A EO-P vs 20P EO-P vs 30P (10A, 20A, and 30A more anterior than EO-A) (30A more anterior than 10A) (20P and 30P more anterior than EO-P)

	TM	
	INITIAL POSITION /tæp/	FINAL POSITION /pæ**t**/
/t/	Posterior movement for Anterior holes Posterior movement for 10P but Anterior movement for 20P and 30P Statistically Significant Differences: A) Location: 30A vs 30P* B) Size: EO-P vs 30P 10P vs 30P (30P more anterior than EO-P and 10P)	Posterior movement for Anterior holes Posterior movement for Posterior holes Statistically Significant Differences: A) Location: 10A vs 10P 30A vs 30P B) Size: EO-A vs 30A 20A vs 30A (30A more anterior than EO-A and 20A)
	/**k**æp/	/pæ**k**/
/k/	Anterior movement for Anterior holes Anterior movement for Posterior holes Statistically Significant Differences: A) Location: 20A vs 20P 30A vs 30P B) Size: EO-A vs 20A EO-A vs 30A 10A vs 30A 10A vs 20A (20A and 30A more posterior than EO-A) (30A and 20A more posterior than 10A)	Posterior movement for 20A and 30A Anterior movement for Posterior holes Statistically Significant Differences: A) Location: EO-A vs EO-P 20A vs 20P 30A vs 30P B) Size: EO-A vs 20A EO-A vs 30A 10A vs 20A 10A vs 30A (20A and 30A more posterior than EO-A) (20A and 30A more posterior than 10A)

APPENDIX D

SUMMARY OF RESULTS: TONGUE TIP (TT) AND TONGUE MEDIUM (TM) MOVEMENT FOR THE PALATAL "FISTULA" CONDITION AFTER FIVE DAYS

	TT	
	INITIAL POSITION /tæp/	FINAL POSITION /pæt/
/t/	Anterior movement for 20A-5 Posterior movement for 20A and EO-A Statistically Significant Differences: 20A-5 vs 20A 20A-5 vs EO-A	Anterior movement for 20A-5 Posterior movement for 20A and EO-A Statistically Significant Differences: 20A-5 vs 20A 20A-5 vs EO-A
	/kæp/	/pæk/
/k/	Posterior movement for 20A-5 Anterior movement for 20A And EO-A Statistically Significant Differences: 20A-5 different than 20A 20A-5 different than EO-A	Posterior movement for 20A-5 Anterior movement for 20A Posterior movement for EO-A Statistically Significant Differences: 20A-5 different than 20A 20A-5 different than EO-A

	TM	
	INITIAL POSITION /tæp/	FINAL POSITION /pæt/
/t/	Posterior movement for 20A-5 Posterior movement for 20A No movement for EO-A Not Statistically Significant Differences: 20A-5 vs 20A 20A-5 vs EO-A	Posterior movement for 20A-5 Posterior movement for 20A and EO-A Not Statistically Significant Differences: 20A-5 vs 20A 20A-5 vs EO-A
	/kæp/	/pæ**k**/
/k/	Anterior movement for 20A-5 Anterior movement for 20A and EO-A Statistically Significant Differences: 20A-5 vs 20A Not Statistically Significant Differences 20A-5 vs EO-A	Anterior movement for 20A-5 Posterior movement for 20A Posterior movement for EO-A Statistically Significant Differences: 20A-5 vs 20A Not Statistically Significant Differences 20A-5 vs EO-A

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BIOGRAPHICAL SKETCH

Viviane Cristina de Castro Marino was born on January 17, 1967, in Brazil. She spent four years at the Sagrado Coração University, where she received her Bachelor of Speech Language Pathology and Audiology degree. She joined the graduate program at the Federal University of São Paulo in 1993 and earned a Master of Science degree in Human Communication Disorders in 1996. While pursing her master's degree, she started working as a faculty professor at the Paulista State University, Marília, Brazil, and joined the research activities developed by the Hospital for Research and Rehabilitation of Cleft Lip and Palate–University of São Paulo, at Bauru. At that time, she became increasingly interested in the nature of speech disorders related to craniofacial anomalies. In 1997, she enrolled in the graduate program at the University of Florida, Department of Communication Sciences and Disorders, and was awarded the doctoral degree in May 2001. After graduation, she will return to Brazil to continue serving as a faculty professor and researcher at the Paulista State University

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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